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**Structural Analysis of Socio-Technical Impacts on Energy Use and
Related Greenhouse Gas Emissions in Korea
Based on Energy Input-Output Tables**

Whan-Sam CHUNG

ABSTRACT

Korea ranks in the top 10 countries for its Greenhouse Gas (GHG) emissions from energy use. What is more important is that the increased rate of Korean GHG emissions has reached the highest in the world since 1990, when global GHG emission mitigation efforts began. More than 80% of the GHG emissions in Korea are produced by the energy sector. Thus, among Korea's policies for global climate change, that for the energy sector is very important. Although Korea does not have binding GHG emission targets under the Kyoto Protocol, it nevertheless declared a voluntary mitigation target in November 2009. However, for countries such as Korea in the non-Annex I group under the Kyoto Protocol, it is more important to have the capability to analyze the emission characteristics in each industrial sector than to engage in declarations pertaining to reductions in total emissions, because this will lead to a better position to prevent loss of economic competitiveness in the post-Kyoto Protocol era. In this respect, this study is beneficial to those countries that are developing the analysis capability.

This study adopted a hybrid input-output (IO) analysis approach in order to quantitatively examine the relationship between economic activity, energy usage, and GHG emissions, along with a model using data from 1985 to 2005 in Korea. Although the IO analysis has inherent limitations and potential for misuse, it has an important function in comprehensive economic studies. The IO analysis provides a useful framework for tracing energy use and other activities such as environmental pollution that are associated with inter-industry activities. For the purpose of the analysis, the original IO analysis table composed of monetary unit is extended into a hybrid IO table that contains both monetary and physical units. Moreover, in this study, an index decomposition analysis (IDA) is applied to analyze the changes in GHG emissions according to time series energy use.

The analysis model has hybrid unit energy IO (E-IO) tables with 90×90 sectors including eight energy sectors, based on the 403 categories of IO tables announced by the Bank of Korea. The sectors were classified into energy, energy intensive, and energy less-intensive groups. Then, the factor decomposition of CO₂ emissions change was performed using the IDA method. The established E-IO model analyzed the characteristics of each energy source used in each sector of the Korean economy, as well as the emissions characteristics of three GHGs (CO₂, CH₄, and N₂O). The compatibility of the estimated emissions was verified in a follow-up comparison with the estimated emissions stated in the national communication report prepared for the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, using the IDA method, the changes in the GHG emissions were categorized into three effects: the energy consumption effect (D_{tot}), social factor effect (D_{soc}), and technology change effect (D_{tech}).

During the E-IO model development process, the requirements of the energy conservation condition and Hawkins-Simon condition were verified as necessary conditions. Additionally, arbitrariness of the IDA results depending on the units (monetary or physical) was avoided because a location where unit problems could occur was not present in the proposed IDA. Even though the concept behind this study is widespread and is composed of the well-organized form by Miller and Blair (1985, 2009), this study bears significance for its real scale E-IO analysis focusing on Korea's economic sector, energy use, and realistic assessment of GHG emissions.

Structural analyses for each year have elucidated the structure of energy use and GHG emissions in each industrial sector in Korea. Sectors 27 (chemical fibers) and 35 (primary iron and steel products) were characterized with relatively low levels of both energy use and GHG emission intensity; however, in these sectors, the induced effect of energy intensity and GHG emission intensity was higher than the direct effect. In the energy group, sectors 9 (hydropower generation)

and 11 (atomic power generation) were inferior to the other sectors in terms of embodied energy intensity, but were superior in terms of GHG emission intensity. Furthermore, sector 12 (town gas) was inferior in terms of GHG emission intensity despite being characterized with a high embodied energy intensity.

The time series analysis of the E-IO tables from 1985 to 2005 demonstrated that the non-energy sectors exhibited a gradual improvement during this period. However, the energy group underwent numerous improvements, but its GHG emission intensity increased during the same period. This suggests that the GHG emissions that were contributed by the energy sectors significantly increased Korea's GHG emissions.

In the IDA, an increase in D_{tot} was the largest effect in the increase of the GHG emissions, whereas D_{tech} had a growing negative effect during 1995 and 2000. However, as time passed, the magnitudes of the three decomposition effects became smaller. This demonstrates that the changes in the GHG emissions relevant to energy use in the intermediate sectors of Korea have gradually stabilized; moreover, it has been demonstrated that this phenomenon was more prominent in the energy sectors. In addition, the relative importance of D_{tot} exhibiting a considerable impact from 1985 to 1995 tended to decrease gradually, whereas the relative levels of importance of D_{soc} and D_{tech} increased during 2000 and 2005.

In addition, the acceptability was verified based on the validity of the analysis results from the whole procedure of energy input-output analysis and decomposition analysis of two sectors: organic basic chemical products and cement and concrete products. Empirical tests were performed using changes in energy consumption, production, process improvements, and new facilities. Although the results exhibited unstable fluctuations in the Divisia index decomposition analysis, it was verified that the entire procedure could provide a useful decision-making basis in understanding each industry's energy consumption and GHG emissions.

This study provides useful information for energy use and GHG emissions by enlarging the current understanding of interactions among energy, emissions, and economic structure. This can assist Korean policy makers and other developing countries through the publication of the IO table, in order for these groups to prepare for GHG reductions.

Contents

ABSTRACT.....	i
Contents	iii
List of Tables	vii
List of Figures.....	ix
Chapter 1. Introduction.....	1
1.1. Background and necessity of the study	1
1.1.1. Korean energy and environment situation.....	1
1.1.2. Necessity of the study	3
1.2 Literature review	7
1.3. Statement of purpose.....	9
1.4. Study structure	9
1.5. Study originality.....	10
References.....	12
Chapter 2. Convertibility of Monetary and Physical Input-Output Analysis and an Application to Energy Sources.....	15
2.1 Energy analysis: IO analysis studies	15
2.2 Typical analysis process.....	16
2.2.1 Process of conventional IO analysis.....	16
2.2.2 Process of E-IO analysis	18
2.3 Inductive evidence to convertibility in E-IO	19
2.4 Application of linkage effect analysis of energy sources.....	21
2.4.1 Composition of an input coefficient matrix in the energy sector	21
2.4.2 Estimation of linkage effect	22
2.5 Conclusion	24
References.....	25
Chapter 3. An Analysis of Sectoral Energy and GHG Emission Intensity in Korea: An Energy IO Approach.....	27
3.1 Introduction	27
3.2 Construction of the E-IO table	29
3.2.1 Composition of the E-IO table	29
3.2.2 Sector rearrangement.....	30
3.2.3 Treatment of energy data.....	31

3.2.4 The producibility condition	32
3.2.5 Prevention of double count error	32
3.3 E-IO analysis	33
3.3.1 Procedure for estimating energy intensity	34
3.3.2 Estimation of the GHG emissions	36
3.4 Results: Creation of inventory database	37
3.4.1 Energy intensity analysis	37
3.4.2 GHG emission intensity analysis	41
3.5 Conclusion	47
References	48
 Chapter 4. A Time-series Energy Input-Output Analysis of Energy Use and Associated GHG Emissions in Korea	51
4.1 Introduction	51
4.1.1 Energy consumptions in Korea	51
4.1.2 Greenhouse gas emissions in Korea	53
4.2 Preceding study review	54
4.2.1 Composition of the E-IO table	54
4.2.2 Validation of the composed E-IO table	55
4.2.3 Selection of the GHGs	57
4.3 Methodology	58
4.3.1 E-IO analysis procedure	58
4.3.2 Modification of the GHG emission factor	59
4.3.3 Validation of estimated GHG emissions	60
4.4 Results	61
4.4.1 Energy use and GHG emission factors	61
4.4.2 Energy and GHG emission intensities from total energy use	63
4.5 Summary and policy recommendations	69
References	70
 Chapter 5. Index Decomposition Analysis of Changes in Energy-related Sectoral GHG Emissions in Korea	73
5.1 Introduction	73
5.1.1 State of Korea's energy and environment	73
5.1.2 Decomposition methods	75
5.1.3 Literature review of the decomposition analysis of energy and the environment	75
5.1.4 Decomposition features	77
5.2 Model for the index decomposition method and data pertaining to energy and	

GHG emissions in Korea	78
5.2.1 Model description.....	78
5.2.2 Korea's energy and GHG emission data: hybrid IO tables from 1985 to 2005	80
5.2.3 Changes in energy intensities	82
5.2.4 Changes in sectoral GHG emission intensities.....	84
5.3 Results and discussions	86
5.3.1 Profile of the explanation of decomposition results	86
5.3.2 Decomposition results of the changes in GHG emissions.....	87
5.3.3 Decomposition analysis of the aggregated data	90
5.4 Conclusion	91
References	93
Chapter 6. Empirical Test of Index Decomposition Analysis.....	97
6.1 Adequacy of the estimated energy data.....	97
6.2 Analysis of social and technical impacts on energy use and GHG emissions.....	97
6.2.1 Overall trends of plotting patterns from 1985 to 2005	97
6.2.2 Selection of distinct sector	99
6.3 Empirical analysis of two specific sectors	101
6.3.1 Comprehensive analysis of sector-18.....	101
6.3.2 Comprehensive analysis of sector-26.....	103
6.4 Conclusion	105
References	106
Chapter 7. Conclusion	107
Appendices.....	111
List of Publications.....	155
Acknowledgement	157

List of Tables

Table 1.1 Trend of total primary energy consumption in Korea (kTOE).....	2
Table 1.2 Trend of total final energy consumption in Korea (kTOE).....	2
Table 1.3 Energy and environment status of Korea in the world (as of 2003).....	3
Table 1.4 Energy intensity of OECD countries (M-TOE/B-2000 US\$).	5
Table 1.5 CO ₂ emission intensity in OECD countries (t CO ₂ /TJ).....	5
Table 1.6 Energy and environment studies using IO analyses.....	7
Table 1.7 Recent weighted decomposition cases of input-output coefficients.....	8
Table 2.1 IO analysis studies applied to energy issues	16
Table 2.2 Structure of two kinds of transaction matrix	20
Table 2.3 Input coefficients matrix of an energy sector (a_{ij}).....	21
Table 3.1 Summary of the rearranged sectors	30
Table 3.2 Comparison of primary energy consumption (kTOE)	31
Table 3.3 Modified GHG emission factors for each energy source (t-CO ₂ -eq./TOE)	37
Table 3.4 The top three sectors in direct and total energy intensities in each group (TOE/M-KRW)	38
Table 3.5 Estimation of GHG emissions in 2000.....	42
Table 3.6 Comparison of GHG emissions in 2000 with the National Communication Report	43
Table 4.1 GHG emissions in Korea (Mt-CO ₂ eq)	53
Table 4.2 Comparison of the primary energy consumption	56
Table 4.3 Modification of the CO ₂ emission factors by energy source.....	60
Table 4.4 Comparison of the estimation tendency for the GHG emissions	61
Table 4.5 Sectoral energy use factor and its GHG emissions factor	62
Table 5.1 Status of Korean economy, energy use, and GHG emissions	74
Table 5.2 Recent decomposition cases with the LMDI method.....	76
Table 5.3 Sector classification of intermediate industries in Korea	81
Table 6.1 Comparison of the primary energy consumption	97
Table 6.2 Comparison of energy consumption of 2 sectors	100

List of Figures

Figure 1.1 GHG emissions in Korea (Mt CO ₂ -eq.).....	3
Figure 1.2 Projection comparison of absolute emission and emission intensity of CO ₂ between Korea and Japan.	6
Figure 1.3 Simplified procedure of E-IO analysis and IDA.....	10
Figure 2.1 Estimation of linkage effect coefficient.	23
Figure 3.1 Basic structure of an E-IO table.....	29
Figure 3.2 Three types of energy use and GHG emission in economic sectors.	33
Figure 3.3 General procedure of E-IO analysis.....	34
Figure 3.4 Ratio of direct to total energy intensity.....	39
Figure 3.5 Sectoral direct energy intensity by 14 energy sources.	40
Figure 3.6 Sectoral embodied energy intensity by 14 energy sources.	40
Figure 3.7 Ratio of direct to total GHG emissions intensity.	41
Figure 3.8 GHG emission factors of 96 sectors.	44
Figure 3.9 Distribution of 96 sectors from direct energy use.....	46
Figure 3.10 Distribution of 96 sectors from embodied energy use.	46
Figure 4.1 Korea's energy flow in 1985 and 2000.....	52
Figure 4.2 Process of time-series E-IO analysis.....	58
Figure 4.3 Embodied energy intensity for three separate groups.....	64
Figure 4.4 Change of the CO ₂ emission intensities during 1985-2000.	66
Figure 4.5 Change of the CH ₄ emission intensities during 1985-2000.	66
Figure 4.6 Change of the N ₂ O emission intensities during 1985-2000.	67
Figure 4.7 Temporal distribution changes in total intensities in each group.....	68
Figure 4.8 Changes in coefficients of slope for each group.	69
Figure 5.1 Trend in final energy consumption in Korea.	73
Figure 5.2 Changes in direct energy intensities between 1985 and 2005.....	83
Figure 5.3 Changes in embodied energy intensities between 1985 and 2005.....	83
Figure 5.4 Changes in direct GHG emission intensities during 1985-2005.	85
Figure 5.5 Changes in embodied GHG emission intensities during 1985-2005.	85
Figure 5.6 Decomposition results of the direct GHG emissions for three effects.....	88
Figure 5.7 Decomposition results of the embodied GHG emissions for three effects.	89
Figure 5.8 Decomposition results for the aggregated changes in GHG emissions.	91
Figure 6.1 Temporal distribution changes in direct intensities in each group.....	98
Figure 6.2 Temporal changes in the relationship between energy and GHG emission intensities.....	100
Figure 6.3 IDA results for the two sectors in energy intensive group.....	101

Chapter 1. Introduction

1.1. Background and necessity of the study

1.1.1. Korean energy and environment situation

Even though the Asian financial crisis of 1997-1998 hit Korea particularly hard, Korea's primary energy consumption more than doubled during the past 15 years, from 93.2 million tons of oil equivalent (M-TOE) in 1990 to 228.6 M-TOE in 2005. This amounts to a 6.2% average annual growth rate (AAGR) in energy consumption, which is comparable to 5.6% AAGR in gross domestic product (GDP) during the same period. With regard to the fuel source, the consumption of high carbon containing coal and oil decreased from 26.2% and 53.8%, respectively, in 1990 to 24.0% and 44.4%, respectively, in 2005 of the total primary energy consumption. In contrast, low carbon containing natural gas and renewable energies, except hydropower, increased from 3.2% and 0.9%, respectively, in 1990 to 13.3% and 1.7%, respectively, in 2005.

Korea's rapid industrialization process over the decade from 1990 to 2000 resulted in an increase in energy consumption in the industrial sector by more than 250% from 36.2 M-TOE in 1990 to 94.2 M-TOE in 2005. Although the increasing number of automobiles has dramatically increased the national energy consumption in the transportation sector, the energy consumption in the industrial sector still outranks the other sectors of national energy consumption. In 2005, the industrial sector accounts for 55.2% of Korea's final energy consumption, followed by the residential and commercial (21.6%), transportation (20.8%), and other (2.4%) sectors.

With regard to the energy type in the final energy consumption, petroleum products constituted the largest share for each user group. Coal was the second most prevalent energy source, although its use remained relatively static between 1985 and 2005 because the consumption of more environmentally friendly town gas and low carbon electricity increased, as shown in Tables 1.1 and 1.2.

According to the energy statistics published by Korea Energy Economics Institute (KEEI) [1], Korea's greenhouse gas (GHG) emissions increased gradually from 247.8 million tons of carbon dioxide (Mt CO₂) in 1990 to 498.9 Mt CO₂ in 2005, in the energy sector. Furthermore, its share in total emission also increased from 81.1% in 1990 to 83.6% in 2005. Korea's GHG emissions, including final demand, amounted to an AAGR of 5.1% in the energy sector from 1990 to 2005. During this period, the GHG emissions from the energy transformation industries and transport industries increased by 10.6% and 5.8% per annum, respectively. However, the rate of GHG emissions fell for the energy industries (3.1%), manufacturing and construction industries (0.4%), and transport industries (1.2%) from 2000 until 2005 compared with the consumption over the entire period (Figure 1.1).

Table 1.1 Trend of total primary energy consumption in Korea (kTOE)

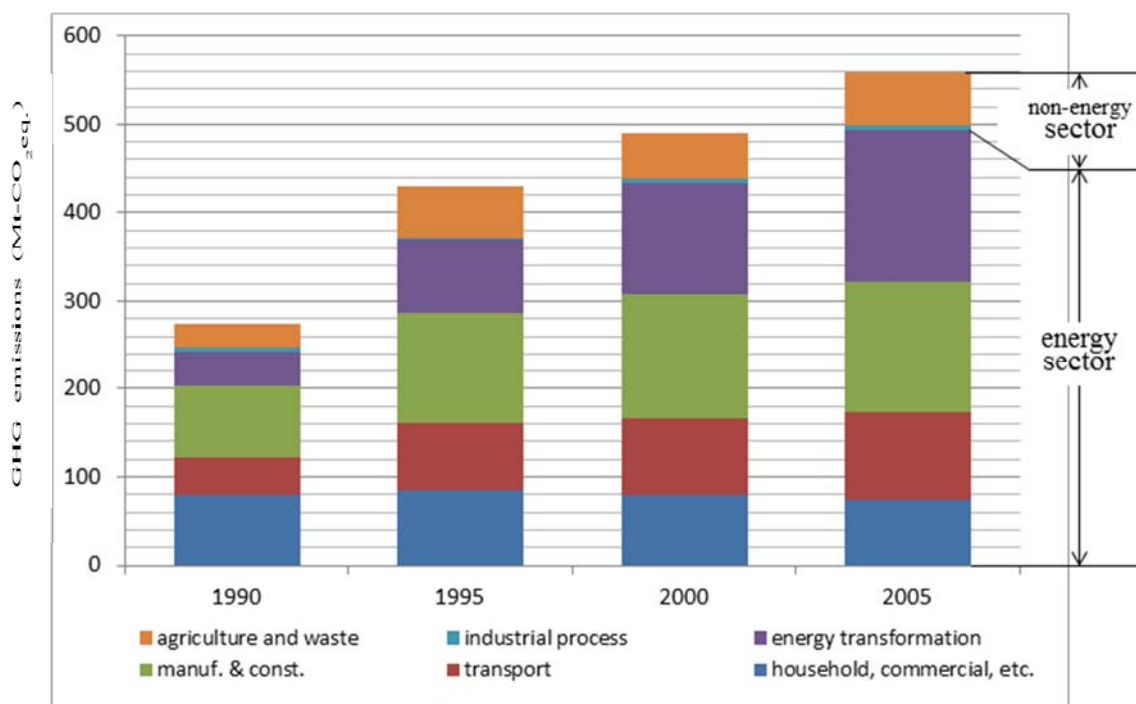
Energy source	1985	1990	1995	2000	2005
Crude petroleum	27,142	50,175	93,955	100,279	101,526
Coal	22,022	24,385	28,091	42,911	54,788
Atomic power generation	4,186	13,222	16,757	27,241	36,695
Water power generation	915	1,590	1,369	1,402	1,297
LNG	-	3,023	9,213	18,924	30,355
Woods and other	2,031	797	1,051	2,130	3,961
Total	56,296	93,192	150,436	192,887	228,622

Source: KEEI, Yearbook of Energy Statistics

Table 1.2 Trend of total final energy consumption in Korea (kTOE)

Sector	Energy source	1985	1990	1995	2000	2005
Industry	Petroleum products	10,697	20,014	36,810	48,193	50,905
	Coal	6,490	10,806	16,244	19,129	21,238
	Electricity	2,812	5,095	8,293	11,374	14,346
	Town gas	15	235	863	3,308	4,655
	Others	-	-	736	1,908	3,222
	Total	20,014	36,150	62,946	83,912	94,366
Residential & Commercial	Petroleum products	3,525	8,876	17,632	13,492	9,437
	Coal	11,399	9,027	1,514	718	1,074
	Electricity	1,155	2,421	4,801	7,891	12,233
	Town gas	69	777	4,607	9,024	12,503
	Others	2,031	872	897	1,245	1,614
	Total	18,179	21,973	29,451	32,370	36,861
Transportation	Petroleum products	6,645	14,086	27,010	30,770	34,983
	Coal	-	-	-	-	-
	Electricity	62	87	138	175	224
	Town gas	-	-	-	-	339
	Others	-	-	-	-	-
	Total	6,707	14,173	27,148	30,945	35,546
Public & Others	Petroleum products	1,712	2,276	1,424	1,140	1,393
	Coal	50	21	-	-	-
	Electricity	333	514	808	1,160	1,785
	Town gas	-	-	125	229	313
	Others	-	1	59	96	577
	Total	2,095	2,812	2,416	2,625	4,068

Source: KEEI, Yearbook of Energy Statistics



Remarks: GHG emission data in 1985 is not available for Korea.

Source: Korea Energy Economics Institute

Figure 1.1 GHG emissions in Korea (Mt CO₂-eq.).

1.1.2. Necessity of the study

According to World Resources Institute (WRI)[2], not surprisingly, Korea ranks 26th in per capita GHG emissions, 12th in total GHG emissions, and first in the world for the GHG emission increase rate during the period from 1990 to 2002 (Table 1.3). Korea's highest increase rate of per capita CO₂ emission was higher than that of Indonesia (97%), Iran (93%), and Saudi Arabia (91%). Furthermore, in terms of the increase rate of non-CO₂ GHG emissions over the same period, Korea ranked second with a 49% increase rate. As of 2000, only Saudi Arabia, which is the largest petroleum exporting country, emitted more non-CO₂ GHGs than Korea.

Table 1.3 Energy and environment status of Korea in the world (as of 2003)

Standings in the World	
Energy	<ul style="list-style-type: none"> • 10th in energy consumption • 7th in oil consumption • 4th in oil import • 2nd in coal and LNG import
Environment (Climate change)	<ul style="list-style-type: none"> • 26th in capita GHG emission • 12th in total GHG emission • 1st in per capita GHG emission increase rate (1990-2002) • 2nd in non-CO₂GHGs emission increase rate (1990-2000)

According to the IEA [3, 4], the Korean CO₂ emissions from energy consumption have decreased to 448.9 Mt CO₂ in 2005 from 462.1 Mt CO₂ in 2004. However, Korea still ranks in the top 10 countries for its GHG emissions from energy use. What is more important is that the increased rate of Korean GHG emissions has reached the highest in the world since 1990, when global GHG mitigation efforts commenced. During that time, especially from 1990 until 2004, Korean emissions of GHGs increased from 226 Mt CO₂ to 462.1 Mt CO₂. The increase rate was 104%, which is significantly higher than the average increase rate worldwide (54%) and that of the OECD countries (17%). Korean GHG emission per capita is the highest amongst the OECD countries.

During the same period, the Korean economy developed significantly with an annual growth rate of 7-8%, and its GDP has grown 2.8 times. When comparing Korea's GHG emission levels with other countries, it must be understood that the Korean rate is out of the average range. Among the OECD countries, the Czech Republic, Germany, Hungary, Poland, and the United Kingdom have succeeded in lowering their GHG emission levels; Denmark, Iceland, Luxemburg, and Sweden have maintained their GHG emission levels. Therefore, Korea must develop its own energy policy with consideration of its economy, as well as with an understanding of its energy and GHG emissions.

As previously discussed, more than 80% of the GHG emissions in Korea have stemmed from the energy sector since 1990 when Korea began reporting its GHG emission statistics. Thus, among Korea's policies for global climate change and its effects, those for the energy sector are critical. The AAGR of the GHG emissions caused through energy consumption has decreased to 3.3% for the period from 2000 to 2005 from that of 5.1% for the 1990 to 2005 period. This demonstrates that the Korean GHG emission situation has begun to improve.

Although the AAGR of GHGs has decreased, the total amount of GHG emissions in Korea has increased. The energy-related GHG emissions are classified as follows: socio-economic factors, energy intensity, and fuel mix (Kaya identity, WRI [2]).

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \quad (1.1)$$

In Eq. (1.1), the first factor, i.e. population, is not a meaningful factor for the decrease of GHGs that result from energy consumption because Korea's population growth is almost the lowest in the world. The next factor, i.e. GDP, is a positive factor for economic development and is a significant demo-economic index. The remaining two factors, i.e. the energy intensity factor and the GHG emission factor, are two important targets that can allow Korea to decrease its GHG emission level. Between these two factors, the third factor, i.e. the energy intensity factor, can be regulated either by shifting to less energy-intensive industries or by promoting more effective energy conservation. Finally, the last factor can be controlled using an appropriate energy mix, e.g. substituting coal and petroleum with low carbon emitting energies such as liquid natural gas (LNG) and renewable energy. However, these types of policy measures in the energy sector require significant social expenditure. Therefore, for cost efficient policy-making, it is necessary to understand the interactions between the economic activities, energy use, and GHG emissions.

The statistics from the IEA [3] regarding the energy consumption of OECD countries demonstrates that Korean energy intensity until the 1980s was well maintained. However, since 1990, it has deteriorated to become three times worse than that of Japan, which has the strongest performance in the OECD countries in 2005 (Table 1.4). However, Korea's GRG emission intensity has been slightly below the OECD country average since 1990 (Table 1.5).

Table 1.4 Energy intensity of OECD countries (M-TOE/B-2000 US\$)

	France	Germany	Italy	Japan	Korea	UK	USA	OECD Average
1975	0.227	0.302	0.196	0.135	0.267	0.247	0.385	0.291
1980	0.223	0.291	0.177	0.123	0.322	0.226	0.351	0.274
1985	0.219	0.272	0.161	0.111	0.287	0.206	0.294	0.244
1990	0.205	0.228	0.156	0.107	0.315	0.179	0.271	0.224
1995	0.205	0.196	0.159	0.112	0.336	0.173	0.258	0.218
2000	0.190	0.178	0.156	0.111	0.348	0.151	0.230	0.201
2005	0.187	0.173	0.16	0.105	0.316	0.133	0.208	0.190

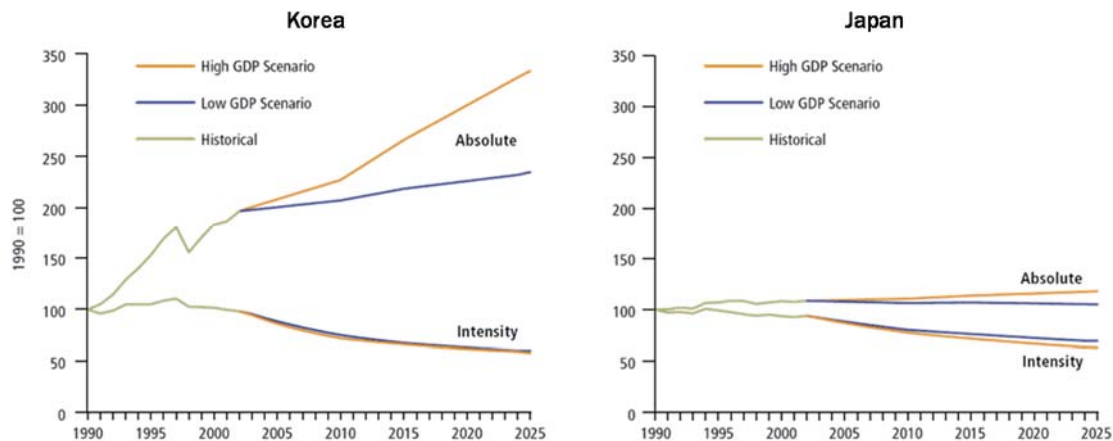
Source: OECD/IEA, Key world energy statistics, 2006.

Table 1.5 CO₂ emission intensity in OECD countries (t CO₂/TJ)

	France	Germany	Italy	Japan	Korea	UK	USA	OECD Average
1975	62.3	74.3	65.4	67.0	75.0	69.4	63.0	64.7
1980	57.5	70.6	65.7	61.1	72.1	68.7	61.7	62.9
1985	42.2	67.8	64.2	57.8	68.4	64.8	61.2	60.5
1990	37.6	64.6	64.8	57.9	58.8	63.7	60.7	58.9
1995	35.7	61.6	61.4	55.2	59.2	57.1	59.4	57.2
2000	35.7	58.6	59.3	54.5	54.2	56.1	59.9	56.9
2005	34.3	57.2	59.4	56.0	53.2	57.2	59.4	56.4

Source: OECD/IEA, Key world energy statistics, 2006.

WRI [2] presented a meaningful graph (Figure 1.2) implying that the GHG emission intensities in 2025 will be less than those in 2002 in both Korea, which is a rapidly developing country, and Japan, which has a mature economy, regardless of the two economic growth scenarios. The amount of GHG emissions expected from Japan in 2025 is almost the same as that produced in 1990 despite the presumed economic growth. However, Korea is expected to increase its GHG emissions by over 250%. This presumption implies that matured countries, such as Japan, are able to establish efficient energy-environment policies based on solid understandings of the mechanisms of economic activities, energy use, and GHG emissions. However, less mature countries, such as Korea, cannot yet reach this point without a steep increase in their GHG emissions. If the global regime on climate change is enforced in Korea, then concrete understandings of the interactions among these factors must be prepared.



Source: Kevin, A.B., Baumert, H., and Jonathan, P., Navigating the numbers: Greenhouse gas data and international climate policy, World Resources Institute (WRI), 2005.

Figure 1.2 Projection comparison of absolute emission and emission intensity of CO₂ between Korea and Japan.

Without appropriate understandings and knowledge regarding the interactions between the economy, energy, and environment, any energy policy designed to manage climate change may have less efficient implementation. The various policy actions that have been undertaken to date have been insufficient to substantially reduce the GHG emissions in Korea's energy use. In order to prevent an international paradigm in the post-Kyoto era, Korea must begin specific actions. Currently, Korea plans to eliminate the policies that were based on common practice as well as social distortions and search for effective and efficient policies.

In general, energy policies are formed based on three levels of statistics. The first level is the national level aggregation data such as national GDP and GHG emissions. The second level is partially grouped data such as primary, secondary, and tertiary industries. The third level is the individual industry data, which is as detailed as possible and includes the fishery processing, steel manufacturing industry, education industry, and so on.

Energy is commonly cited as a production factor instead of labor. Thus, reducing energy consumption causes the national GDP to decline. Therefore, the national energy policy should be constructed in order that it has a smaller influence on the GDP while simultaneously achieving the policy goals. It is known that a combination of the third statistics and IO analysis is a useful tool for economic analysis and it will be a powerful method of building national policy.

As a first step in establishing an efficient policy in energy conservation and mitigation of GHG emissions, it is important to understand the interrelations between the economic activities, energy use, and GHG emissions. Then, a fundamental model describing the national energy and GHG emission situation should be prepared with harmonization of the census and estimation. The energy input-output (E-IO) analysis will have an important function in the estimations that will be used in constructing the energy and climate change policies, because the input-output

model is a well-known quantitative economic technique that represents the interdependencies between different sectors of a national economy or different regional economies.

1.2 Literature review

There are numerous cases around the world that use an energy and/or environmental analysis with an IO approach. Table 1.6 presents some examples, which are described in more detail here. Energy analyses and environment analyses have been performed simultaneously for various countries: Gay and Proops [5] performed important research on the energy analysis and the environmental analysis for CO₂ emissions that result from the economic activities of thirty-eight sectors using England's IO table from 1984. Lenzen [6] reported on the intensities of primary energy and GHGs (CO₂, CH₄, N₂O, CF₄, and C₂F₆) in terms of MJ/\$ and kg CO₂ equivalent/\$, respectively, using Australia's IO table from 1992/93. Cruz [7] used Portugal's IO table to analyze the interactions between energy, environment, and economy.

Japan has also conducted studies using energy and environment analyses using IO tables. The following three reports are the prominent researches that introduced the key cases. The first was written by Keio University's Keio Economic Observatory [8]; the second was written by the Center for Global Environmental Research (CGER) in the National Institute for Environmental Studies (NIES) [9]; and the third case was prepared by the Socio-economic Research Center in the Central Research Institute of Electric Power Industry (CRIEPI) [10]. Based on these reports, Kim [11], Nansai [12], and Hondo [13] issued their academic papers.

Table 1.6 Energy and environment studies using IO analyses

Units in IO table Time span	Single unit	Hybrid units
One year	Gay and Proops (1993), Lenzen (1998), Park (1999), Cruz (2002), Kim (2006), Hondo (2002), Nansai (2003), Kim (2004)	Choi and Lee (2004) Chung, Tohno, and Shim (2009)
Time series	Tsukamoto (2008), Wiedmann (2010)	Kim (1998) Chung and Tohno (2009)

Park [14] and Kim [15] estimated the amount of CO₂ emissions caused by final energy consumption. Kim [16] composed E-IO tables for coal, petroleum, gas, and electric power using IO tables from 1985, 1990, and 1995. Using these tables, Kim analyzed the amount of energy input and the amount of CO₂ emissions from 18 non-energy sectors. Choi and Lee [17] analyzed the energy consumption of 28 non-energy sectors that used five primary energy sources and 11 final energy sources in order to determine the amount of CO₂ emission accumulated in Korea's export goods. In order to achieve this, a combined IO table of CO₂ emissions was composed. Chung, Tohno and Shim [18] constructed a 96×96 hybrid E-IO table using energy units for each energy sector using the Korean IO table from 2000. This study was extended further back to 1985 by Chung and Tohno [19]. While Tsukamoto [20] and Wiedmann [21] studied time series with single unit IO tables to assess the CO₂ emission from

three types of power plant through LCA and to distinguish GHG emissions embodied in UK trade, respectively.

For time series IO data, decomposition analyses have been widely used to identify the influencing factors in terms of energy and CO₂ emissions. Structural decomposition analyses (SDA) and index decomposition analysis (IDA) are typically used as preferred methods of decomposition analysis. In IDA, the arithmetic mean Divisia index (AMDI) and the log mean Divisia index (LMDI) methods are appropriate to use for the weight function. However, Ang [22] noted that the AMDI methods have two shortcomings: first, they fail the factor-reversal test; second, they fail when the data set contains zero values, e.g. when an energy source begins or ceases to be used in a sector during the study period. The LMDI can be shown to converge when the zero values in the data set are replaced by small positive numbers, but the AMDI does not have this convergence property. Thus, the LMDI method is the preferred IDA method from both theoretical and practical viewpoints. The results given through the multiplicative decomposition and additive decomposition are related by a simple formula and are interchangeable.

The most common application areas for LMDI analyses are energy demand and supply analyses, as well as analyses of energy-related GHG emissions. Most recent studies have concentrated on the decomposition of national CO₂ emissions and emission intensities of the industrial and power sectors (Table 1.7). A more detailed review is presented in Chapter 5.

Besides numerous examples of decomposition studies with aggregated coefficients for national CO₂ emissions (or emission intensities), Lin et al. [23] of Taiwan and Sands and Schumacher [24] of Germany are notable examples that have used input-output tables. Rhee and Chung [25] confined their input-output analysis to Korean and Japanese CO₂ emissions and attempted to analyze the interrelationship of CO₂ emissions via international trade. The sources of change in GHG emissions were categorized into three major composite factors: fuel efficiency, production techniques, and final demand. For this decomposition analysis, they also used the mean rate-of-change index (MRCI) rather than the mean Divisia index (MDI). Chung, Tohno and Choi [26] decomposed the changes that affect GHG emissions into three factors (the energy consumption effect, the social effect, and the technological effect) using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005 in Korea.

Table 1.7 Recent weighted decomposition cases of input-output coefficients

Researcher	Publication year	Country/Region	Calculation	Time span	Application
Lin et al.	2006	Taiwan	Additive LMDI	1991-2001	CO ₂ emissions
Rhee and Chung	2005	Korea and Japan	MRCI	1990-1995	CO ₂ emissions
Sands and Schumacher	2009	Germany	Additive LMDI	1995-2006	GHG emissions
Chung, Tohno, and Choi	2011	Korea	Multiplicative LMDI	1985-2005	Energy intensity and GHG emissions

1.3. Statement of purpose

The overall objective of this study is to establish a model that determines the relationship between economic activity, energy use, and GHG emission in Korea. Estimates are presented for energy use over time and changes in GHG emission patterns, followed by an analysis of the influencing factors. Furthermore, the socio-technical impacts on industry are also analyzed. This study will provide an intellectual framework for future studies in predicting changes in energy use and GHG emissions according to economic activity.

For this purpose, the E-IO approach was adopted because it can offer insights to the relationships between the economy, energy, and GHG. The E-IO tables in this study were constructed using the hybrid approach. The first objective of this study is to examine the convertibility of monetary IO and physical IO, and to develop hybrid units in E-IO tables for the reference year. This process is described as follows. An E-IO table was derived from an inter-industry transaction table from 2000. Based on this hybrid IO table, the interactions between the economic sector, energy sources, and GHG emissions were analyzed. Note that the IO table used in this study was issued by the Bank of Korea (BOK) in 2003. When this study commenced, the 2005 inter-industry survey table had not been released. This table serves as the foundation for the analysis of the GHG emissions according to the industry.

The second objective is to measure the changes in GHG emissions according to industry over time. In accordance with the aforementioned process, E-IO tables were created for the years from 1985 to 2005. In order to consider the changes in industry classification standards and the value of money over time, identical conditions were applied with conversions from the current values, which vary over time, into time-independent constant units. During this stage of research, the inter-industry transaction table of 2005 was announced.

Furthermore, the energy and climate change policies affect many aspects and alter the structure of economies. Therefore, this requires a comprehensive approach when examining the policies. The index decomposition analysis (IDA) provides a tool for the approach that uses IO tables. In order to identify the influencing effects, an IDA was performed for the GHG emissions derived from the time series E-IO tables.

The third objective is to verify the usefulness of the proposed model by conducting empirical analyses of the social and technical effects for two significant industries using the IDA.

1.4. Study structure

This study is organized as follows (Figure 1.3). Chapter 2 reviews the typical analytical processes of both the conventional input-output approach and the input-output approach with hybrid units. The convertibility of the two approaches is demonstrated using an energy model that includes a monetary unit and a physical unit (calorific value) for the input-output table. Chapter 3 constructs a 96×96 hybrid energy input-output (E-IO) table using energy unit for each energy sector from the Korean IO table for 2000 developed by the BOK in 2003. This process is represented by the yellow boxes in Figure 1.3. Using this E-IO table, the energy and

GHG emission intensities (both direct and embodied) that are caused by energy use are estimated for each sector. Using the verification and validation tests in Chapters 2 and 3, four sequential 96×96 hybrid unit E-IO tables for 1985, 1990, 1995, and 2000 are generated in Chapter 4. Chapter 5 analyzes the changes in the GHG emissions in Korea from 1985 to 2005 as represented by the loop of red boxes in Figure 1.3. Based on the E-IO results, the changes are decomposed into three factors, i.e. the energy consumption effect, the social effect, and the technological effect, using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005 as indicated by the process of green boxes in Figure 1.3. Chapter 6 presents an empirical study of the structural analysis of social and technical effects for two sectors. Chapter 7 concludes the paper by providing policy implications for the transition to a low carbon economy in Korea.

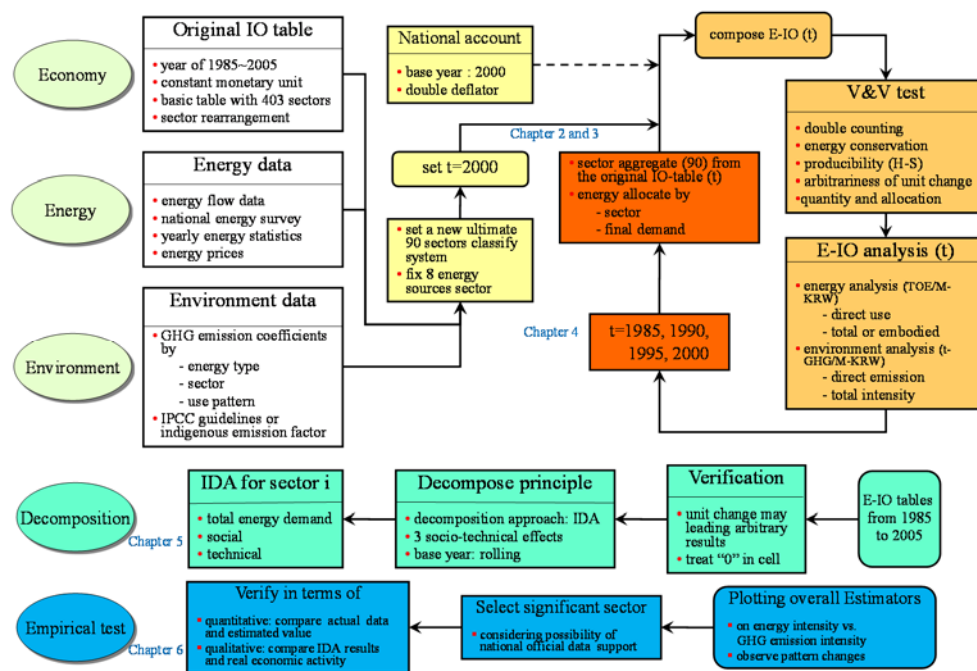


Figure 1.3 Simplified procedure of E-IO analysis and IDA.

1.5. Study originality

Hybrid unit IO analyses provide useful frameworks for tracing energy consumption and other related characteristics such as GHG emissions or flows of physical materials associated with inter-industry activities. National policies on energy and the environment frequently require databases that use physical units rather than monetary units. Thus, the E-IO approach is much more suitable for analyzing the energy and GHG emissions compared with conventional input-output models because it can manage data that is measured in physical units, such as specifying the technical coefficients in tons of oil equivalent (TOE) as inputs, required per monetary worth of an industry's output, and per TOE output in energy industry. The E-IO table, as well as the conventional IO table, is beneficial for evaluating energy consumption because it is well suited to consider recursive impacts; but it can be applied straightforwardly to an

assessment in physical form. The conventional IO analysis suffers from a shortcoming of calculation in monetary form.

This study adopts the hybrid IO approach for the analysis of energy use from 1985 to 2005 in Korea. The IDA is used to analyze the changes in GHG emissions according to time series energy use. This study provides useful information for energy and climate change policies in Korea through the elucidation of the quantitative relationship between the economic activity, energy use, and GHG emissions. This study can be easily applied not only to the Korean policy-making group, but also to other developing countries in order to prepare a new global paradigm on energy and the environment if the relevant IO tables and statistics are available.

The concept behind this study is already known through the work of Bullard and Herendeen [27] and Miller and Blair [28]. Although it is based on the existing methodology, this study is significant for its overwhelming trial in the composition of reliable real scale hybrid unit E-IO tables from 1985 to 2005 and in its attempt to analyze the entire horizon of E-IO tables. The originality of this study is explained in detail as follows.

- In Korea, the BOK manages the economic data while KEEI manages the energy and GHG emission data. These two institutions use different periods and different methods to classify the economic sectors in publishing census data. Therefore, previous studies that have used both BOK and KEEI data have only focused on a few classified sectors. Because this study estimates the hybrid unit E-IO tables from 1985 to 2005 using the BOK data only, the composition of higher resolution tables was possible with the ability to publish additional E-IO tables.
- First, in building the serial hybrid unit E-IO tables, this study produces hybrid unit E-IO tables with real prices (in KRW at year 2000 prices), which include the energy data, for all research years from 1985 to 2005. It is not easy to convert the normal price data into real price data for non-consecutive input-output tables, and the BOK does not provide real price tables for all research years. Further complicating this task, the total energy demand in the input-output table does not match the total primary energy or final energy consumption in the energy balance table provided by KEEI [1] because the accounting rules of these two data sources differ. In order to connect the input-output table and the energy balance table, this research identifies the total demand and total supply for each energy source in the energy balance, which aligns with the accounting concept of the input-output table. This process ensures usefulness of the hybrid unit E-IO table.
- Second, in addition to the typical sector category, this research suggests sector grouping according to their characteristics in the energy input structure. This work identifies and presents three groups in the hybrid unit E-IO tables. Information regarding the energy-intensive group can benefit energy policies to improve their effectiveness. This sector grouping has never been attempted previously; thus, it provides further originality to this research. The sector characteristics in the energy input structure are assessed using the distance function of energy intensity, which simultaneously considers the individual sector's final energy input per total input and final energy input per total energy input in terms of monetary units. This data building process is original and has been not been used in the existing literature.

- This study performed the entire process of E-IO analysis based on the hybrid unit E-IO tables from 1985 to 2005. Empirical analyses that demonstrate the usefulness of the E-IO analysis are also included with the routine analyses in this process.
- For the characteristics of the GHG emissions according to sector, not only the intensity of CO₂, but also those of CH₄ and N₂O, which are also known as direct impact compounds, are analyzed. This research analyzes the GHG emissions from the E-IO tables that offer equally spaced time series data for GHG emissions for all periods. This analysis has originality in producing detailed GHG emission data that are matched with the E-IO table format and that consider the differences in GHG emissions characteristics for each sector and energy.
- Typical decomposition analyses do not analyze more than pair-wise comparisons of GHG emissions for two consecutive periods, but this research adopts a rolling base year method and compares multiple time series data. This research enables the determination of inclining or declining trends of dominant effects. The interpretation of the trend is undertaken through the selection of specified sectors and empirical analyses are conducted in order to demonstrate the social and technological impacts on GHG emissions.

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Chapter 2. Convertibility of Monetary and Physical Input-Output Analysis and an Application to Energy Sources

Convertibility of Monetary and Physical Input-output Analysis- an Application to Energy Sources -, *Korean J. of LCA*, 2008;9(1): pp47-55

In the midst of the increasing importance of the LCA concept, an input-output approach is emerging as a useful methodology to assure the robustness of a solution. An input-output analysis is based on an input-output table using monetary units. Nowadays, the importance of a material flow analysis is increasing. Thus, attempts to construct an input-output table with hybrid units reflecting the physical units have been made. In this study, typical analytical processes of both the conventional input-output approach and the input-output approach with hybrid units are compared. The convertibility of these approaches is demonstrated using an energy model, including a monetary unit and an energy unit, for an input-output approach. Additionally, the linkage effects of various energy sources are analyzed using an E-IO table.

2.1 Energy analysis: IO analysis studies

The IO table demonstrates exchanges of goods and services between industrial sectors in matrix form; Wassily Leontief won the Nobel Prize in 1973 for developing this model. This table is mostly presented using monetary units and has been applied broadly to energy analyses beyond economic analyses because of its high usability with a system of linear equations.

There have been many studies internationally on an energy analysis based on a conventional IO analysis. The following are representative examples. Studies of Wright [1] and Bullard and Herendeen [2], which used US IO tables to determine the primary energy requirements of all sectors, have been regarded as the first ones. Peet et al. [3] performed an energy analysis of direct and indirect household energy consumption in New Zealand from 1974 to 1980. Park and Heo [4] used a process analysis for energy intensive products, and applied an IO analysis to other energy consumption products by referring to Lenzen [5].

Contrary to the above analysis, the following studies relied on the hybrid unit IO model. Miller and Blair [6] wrote a well-organized textbook on E-IO analysis. Pachauri and Spreng [7] determined the indirect energy requirement of India's households according to private final consumption expenditures based on India's IO tables of 1983/84, 1989/90, and 1993/94 (Table 2.1).

Table 2.1 IO analysis studies applied to energy issues

Conventional IO	Hybrid IO
Wright(1974) Bullard and Herendeen(1975) Peet et al.(1985) Park and Heo(2007)	Miller and Blair(1985) Pachauri and Spreng(2002)

2.2 Typical analysis process

2.2.1 Process of conventional IO analysis

An IO table is classified by intermediate demand sectors with the value added derived from goods or services purchased from related sectors and final demand sectors, such as household or government sectors. For instance, the thermal power generation sector provides electricity as its output to almost every industrial sector by receiving input from energy sectors such as coal or fuel oil, and non-energy sectors such as machinery & equipment or plastic products.

Therefore, the original model can be defined with the total sum of an intermediate demand and the final demand, as shown in Eq. (2.1):

$$x_i \equiv \sum_j z_{ij} + y_i \quad (2.1)$$

where x_i is the total production of sector i , z_{ij} is the number of transactions in sector j after producing sector i , and y_i is the final demand of sector i .

When an input ratio such as Eq. (2.2) is introduced into this definition, an efficient modeling equation can be expressed.

$$a_{ij} = z_{ij}/x_j, \text{ for all } i \quad (2.2)$$

where a_{ij} is the ratio of input, i to j , to the total output of sector j .

Here, a_{ij} is a linear relation coefficient that reflects the technological requirements of production by sector j for the inputs from sector i ; a_{ij} is known as a 'technological coefficient' or 'input coefficient'. For example, if sector i is 'fuel oil', and sector j is 'thermal & self-power generation', then a_{ij} is the (average) quantity of fuel oil needed to produce one unit of thermal & self-power generation. Or if we express our relationships in terms of economic value rather than physical quantity, it means the monetary value of the fuel oil consumed to produce one unit of monetary worth of an average thermal & self-power generation.

When Eq. (2.2) is introduced into Eq. (2.1), Eq. (2.1) can be redefined as follows:

$$x_i \equiv \sum_j a_{ij} x_j + y_i \quad (2.3)$$

The IO approaches seen above were devised by Wassily Leontief in 1930. This was later explained using the compact notation of linear algebra. To demonstrate economic activities of groups that are desegregated by n sectors, the following matrix must be defined: let \mathbf{X} be a vector $n \times 1$ of goods required for the total output of the economy, \mathbf{Y} be a vector $n \times 1$ of goods required to satisfy the final demand, and \mathbf{A} be a matrix $n \times n$ of the input coefficients for the economy. Eq. (2.3) can then be expressed as the following linear equation:

$$\mathbf{X} = \mathbf{AX} + \mathbf{Y} \quad (2.4)$$

Here, \mathbf{AX} expresses an intermediate demand of economic activity, and \mathbf{Y} denotes the final demand. If Eq. (2.4) is solved for matrix \mathbf{X} , it becomes

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{Y} \quad (2.5)$$

where $(\mathbf{I} - \mathbf{A})^{-1}$ is known as a 'Leontief inverse matrix' or simply an 'inverse matrix'.

The inverse matrix includes all the direct and indirect requirements for production in the economy that are necessary to satisfy a certain vector of the final demand commodities. Here, Eq. (2.5) can be expanded as an infinite geometric series:

$$(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots \quad (2.6)$$

This series is convergent if \mathbf{A} satisfies the same conditions stated in chapter 3.2.4. A substitution of Eq. (2.6) into Eq. (2.5) gives

$$\mathbf{X} = \mathbf{Y} + \mathbf{AY} + \mathbf{A}^2\mathbf{Y} + \mathbf{A}^3\mathbf{Y} + \dots \quad (2.7)$$

We can decompose the total demand for n goods produced in the economy as follows:

- 1) \mathbf{Y} is required for the final demand (i.e., by consumers).
- 2) \mathbf{AY} is needed to produce goods \mathbf{Y} . This is the 'first-round indirect effect'.
- 3) $\mathbf{A}^2\mathbf{Y}$ is needed to produce goods \mathbf{AY} . This is the 'second-round indirect effect'.
- 4) $\mathbf{A}^3\mathbf{Y}$ is needed to produce goods $\mathbf{A}^2\mathbf{Y}$. This is the 'third-round indirect effect'.

In the energy and environment analysis, the energy and environment emission intensity (J/\$, kg-CO₂/\$, etc.) must be multiplied on the right side of Eq. (2.5). Clearly, the process traces inputs or outputs back to the primary resources; the first term of energy inputs or environmental loads are the direct energy requirement or load, respectively; and the subsequent infinite terms of energy inputs or environmental loads are the indirect energy requirement or emission, respectively. The total energy requirement or environmental load can be divided into direct and indirect terms. The total energy requirement is called the embodied energy.

2.2.2 Process of E-IO analysis

An E-IO analysis is often concerned with the energy measured in physical units, for example, TOE or some other convenient energy units and non-energy flows in money.

The basic process of the E-IO method was introduced in detail by Miller & Blair (1985) and applied to energy systems by Kim (1998), Pachauri and Spreng (2002), and Choi and Lee (2004).

As may be expected, one way to obtain transaction amounts in physical units is to first compute the total monetary requirement by a conventional IO analysis, and convert these values into TOE by means of prices relating money outputs to energy outputs.

This study explains briefly the basic concept of analyzing the linkage effects for each energy source. To calculate the energy and environmental inventories caused by economic activities using E-IO mixed with heterogeneous units, additional definition of the matrices and vectors are needed as follows:

\mathbf{Z}^* is an $n \times n$ matrix, which is a new transaction matrix, because k energy sectors in a conventional IO table are changed row-wise from the monetary price to the energy unit. Thus, this matrix has the original inter-sector transaction matrix \mathbf{Z} in the non-energy sectors, and the energy rows are replaced by the corresponding rows in energy flow matrix \mathbf{E} .

\mathbf{X}^* and \mathbf{Y}^* are $n \times 1$ vectors, which designate the total output and final demand, respectively. These two vectors are also mixed with monetary and energy units according to the sectors.

\mathbf{F}^* is an $n \times 1$ vector and is an artificial vector to isolate the energy rows in a matrix manipulation. The definitions of these quantities are as follows:

$$Z_i^* = \begin{cases} E_k, & \text{for energy rows} \\ Z_j, & \text{for non - energy rows} \end{cases} \quad (2.8)$$

$$X_i^* = \begin{cases} F_k, & \text{for energy rows} \\ X_j, & \text{for non - energy rows} \end{cases} \quad (2.9)$$

$$Y_i^* = \begin{cases} e_k, & \text{for energy rows} \\ y_j, & \text{for non - energy rows} \end{cases} \quad (2.10)$$

$$F_i^* = \begin{cases} F_k, & \text{for energy rows} \\ 0, & \text{for non - energy rows} \end{cases} \quad (2.11)$$

\mathbf{E} is a $k \times n$ matrix and designates the energy flows. \mathbf{E}_y and \mathbf{F} are $k \times 1$ vectors of physical units designating the energy consumed by the final demand and total energy consumption in the economy, respectively. Hence, the total amount of energy consumed (and produced) by the economy means the addition of energy (of each type depicted by the rows of \mathbf{E}_i and \mathbf{E}_y) consumed by intermediate sectors and that consumed by the final demand. This can be shown as follows:

$$\mathbf{E}_i + \mathbf{E}_y = \mathbf{F} \quad (2.12)$$

When this definition is used, the corresponding matrices, $\mathbf{A}^* = \mathbf{Z}^* (\widehat{\mathbf{X}^*})^{-1}$ and $(\mathbf{I} - \mathbf{A}^*)^{-1}$, can be calculated easily. The hat (^) denotes the diagonal matrix of the vector.

However, these matrices have different characteristics from the traditional Leontief model. For example, the input coefficient matrix \mathbf{A}^* indicates the direct requirement and inverse coefficient matrix $(\mathbf{I} - \mathbf{A}^*)^{-1}$, meaning the total requirements have different elements because these are mixed matrices of heterogeneous units.

$$\mathbf{Z}^* = \begin{bmatrix} toe & toe \\ \$ & \$ \end{bmatrix}; \mathbf{Y}^* = \begin{bmatrix} toe \\ \$ \end{bmatrix}; \mathbf{X}^* = \begin{bmatrix} toe \\ \$ \end{bmatrix}; \mathbf{F}^* = \begin{bmatrix} toe \\ \$ \end{bmatrix}$$

When calculating an input coefficient matrix, it is composed of four elements of heterogeneous characteristics, as shown in Eq. (2.13).

$$\mathbf{A}^* = \mathbf{Z}^* (\widehat{\mathbf{X}^*})^{-1} = \begin{bmatrix} toe/toe & toe/\$ \\ \$/toe & \$/\$ \end{bmatrix} \quad (2.13)$$

The $(\mathbf{I} - \mathbf{A}^*)^{-1}$ matrix has the same characteristic as \mathbf{A}^* shown in Eq. (2.13).

2.3 Inductive evidence to convertibility in E-IO

A conventional IO table of a single unit based on money and a hybrid E-IO table combined with various kinds of units produce the same analytical results. Yet, an input coefficients matrix is manipulated based on the price information according to the sectors. This can be easily shown through the following example.

To illustrate that the two different tables lead to the same results, two transaction matrices are assumed: a homogeneous unit conventional IO table and a hybrid E-IO table composed of two kinds of units (Table 2.2).

Sectors e-1 and e-2 denote the energy sector, and those of m-3 and m-4 designate the non-energy industry sector. In the elements of the transaction matrix, m_{ij} is a value expressed as a monetary unit, and e_{ij} is a value expressed as an energy unit (e.g., joules, calories, TOE, etc.). In addition, mx_i is in a monetary unit and ex_i is a value expressed as an energy unit in the total output column. The energy input coefficient is a value that divides m_{ij} expressed as a monetary unit by energy price p_i , under the assumption that p_i is constant irrespective of sector j .

Table 2.2 Structure of two kinds of transaction matrix

I	e-1	e-2	m-3	m-4	$\sum_i w_{i,j}$	II	e-1	e-2	m-3	m-4	$\sum_i w_{i,j}$
e-1	$m_{1,1}$	$m_{1,2}$	$m_{1,3}$	$m_{1,4}$	mx_1	e-1	$e_{1,1}$	$e_{1,2}$	$e_{1,3}$	$e_{1,4}$	ex_1
e-2	$m_{2,1}$	$m_{2,2}$	$m_{2,3}$	$m_{2,4}$	mx_2	e-2	$e_{2,1}$	$e_{2,2}$	$e_{2,3}$	$e_{2,4}$	ex_2
m-3	$m_{3,1}$	$m_{3,2}$	$m_{3,3}$	$m_{3,4}$	mx_3	m-3	$m_{3,1}$	$m_{3,2}$	$m_{3,3}$	$m_{3,4}$	mx_3
m-4	$m_{4,1}$	$m_{4,2}$	$m_{4,3}$	$m_{4,4}$	mx_4	m-4	$m_{4,1}$	$m_{4,2}$	$m_{4,3}$	$m_{4,4}$	mx_4

Herein, the input coefficient matrix on the right side of Table 2.2 has different unit values divided by four elements, as shown in Eq. (2.13). Their expressions are as follows:

1) for a sector from energy to energy representing $\frac{toe}{toe}$,

$$a'_{i,j} = \frac{e_{i,j}}{ex_j} = \frac{(m_{i,j}/p_i)}{(mx_j/p_j)} = \frac{m_{i,j} p_j}{mx_j p_i} = a_{i,j} \frac{p_j}{p_i} \quad (2.14)$$

2) for a sector from energy to non-energy representing $\frac{toe}{\$}$,

$$a'_{i,j} = \frac{e_{i,j}}{mx_j} = \frac{(m_{i,j}/p_i)}{mx_j} = \frac{m_{i,j}}{mx_j} \frac{1}{p_i} = a_{i,j} \frac{1}{p_i} \quad (2.15)$$

3) for a sector from non-energy to energy representing $\frac{\$}{toe}$,

$$a'_{i,j} = \frac{m_{i,j}}{ex_j} = \frac{m_{i,j}}{(mx_j/p_j)} = \frac{m_{i,j}}{mx_j} p_j = a_{i,j} p_j \quad (2.16)$$

4) for a sector from non-energy to non-energy representing $\frac{\$}{\$}$,

$$a'_{i,j} = \frac{m_{i,j}}{mx_j} = a_{i,j} \quad (2.17)$$

As shown above, through the price vector of each energy source, the conventional input coefficients matrix can be simply converted into the coefficients of the E-IO model. Obviously, the results can be presumed to be in diversified form owing to the different dimensions in both matrices. The concept of Eqs. (2.14) – (2.17) will be applied to a combined unit model of two or more units. Therefore, the values for the energy sectors can be used as inherent physical units to prepare an initial IO table to perform the energy analysis using an IO analysis.

To estimate the co-relationships among each energy source, this study used an IO table with heterogeneous units: which are the physical units of TOE for energy sectors and money transaction units for non-energy sectors.

2.4 Application of linkage effect analysis of energy sources

2.4.1 Composition of an input coefficient matrix in the energy sector

Regarding the energy flow in the energy sector, for primary energy such as coal, crude petroleum, and natural gas, the energy input is little, while the energy output becomes a large amount (that is, a_{ii} has small values). On the contrary, non-primary energy such as naphtha, gasoline, fuel oil, and thermal & self-power generation has plenty of energy input (that is, a_{ij} has large values). Atomic power generation has an especially huge amount of energy output but a small amount of energy input. Table 2.3 shows the extraction of a_{ij} of 14 energy sectors in the Korean E-IO table from 2000 described in chapter 3.

Table 2.3 Input coefficients matrix of an energy sector (a_{ij})

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.0E+00	0.0E+00	0.0E+00	1.2E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E+00	0.0E+00	0.0E+00	3.1E-01	0.0E+00
2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.1E-01	8.7E-01	7.6E-01	1.5E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E+00	0.0E+00	0.0E+00
4	0.0E+00	0.0E+00	0.0E+00	2.0E-03	0.0E+00	0.0E+00	0.0E+00	1.0E-03	0.0E+00	1.9E-01	0.0E+00	3.9E-05	0.0E+00	0.0E+00
5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E-05	3.5E-03	1.3E-04	5.8E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
6	1.5E-05	0.0E+00	0.0E+00	3.6E-04	1.4E-04	1.5E-02	6.7E-04	7.0E-04	9.2E-04	8.1E-04	6.0E-04	3.1E-04	1.4E-04	0.0E+00
7	2.1E-04	0.0E+00	0.0E+00	2.9E-03	4.0E-03	3.5E-02	2.0E-02	2.0E-02	1.0E-02	4.4E-01	5.3E-03	2.8E-02	2.6E-01	0.0E+00
8	2.8E-05	0.0E+00	0.0E+00	4.6E-03	4.0E-04	1.5E-03	1.2E-03	1.2E-01	2.1E-03	1.6E-03	8.9E-04	8.6E-04	7.3E-04	0.0E+00
9	1.0E-05	0.0E+00	0.0E+00	1.4E-05	1.7E-05	4.1E-05	5.6E-05	1.9E-05	4.6E-03	2.8E-05	3.2E-04	1.0E-04	1.4E-04	0.0E+00
10	2.4E-04	0.0E+00	0.0E+00	4.0E-04	5.3E-04	2.9E-03	2.1E-03	8.0E-04	2.4E-03	4.9E-02	9.9E-03	2.6E-03	3.2E-02	0.0E+00
11	1.9E-04	0.0E+00	0.0E+00	2.5E-04	3.0E-04	8.9E-04	1.1E-03	4.2E-04	3.9E-03	4.8E-03	1.3E-02	1.9E-03	2.9E-03	0.0E+00
12	0.0E+00	0.0E+00	0.0E+00	7.3E-06	0.0E+00	0.0E+00	0.0E+00	4.9E-07	0.0E+00	2.0E-01	0.0E+00	2.0E-03	4.1E-02	0.0E+00
13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-07	3.9E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.6E-01	0.0E+00
14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Remarks: Energy sources are numbered as follows: 1-Coal, 2-Crude petroleum, 3-Natural gas, 4-Coal products, 5-Naphtha, 6-Gasoline, 7-Fuel oil, 8-Miscellaneous petroleum refinery products, 9-Water power generation, 10-Thermal & self-power generation, 11-Atomic power generation, 12-Town gas, 13-Heat, and 14-Woods.

Figures larger than 1, such as $a_{1,4}$ and $a_{1,10}$, occurred in the carry-over of energy between years.

2.4.2 Estimation of linkage effect

2.4.2.1 Linkage effects

The linkage effects have two viewpoints: one is the backward linkage (*BL*) effect or power of dispersion, which illustrates the degree of purchasing intermediate goods from other industries, and the other is the forward linkage (*FL*) effect or sensitivity of dispersion, which shows the degree of providing intermediate goods to other industries.

In a conventional IO analysis, the linkage multiplier is used to measure the aforementioned effects. The linkage multiplier for each energy source is calculated using the elements of Leontief's inverse matrix, as shown in Eqs. (2.18) and (2.19). Eqs. (2.18) and (2.19) denote the row-wise averages of b_{ij} and column-wise b_{ij} with respect to the average of the total technological coefficients matrix, respectively.

Let \mathbf{B} be an inverse matrix, $(\mathbf{I}-\mathbf{A}^*)^{-1}$, whose element is b_{ij} , then

$$FL\ coefficient = \frac{\frac{1}{n}\sum_i b_{ij}}{\frac{1}{n^2}\sum_{ij} b_{ij}} \quad (2.18)$$

$$BL\ coefficient = \frac{\frac{1}{n}\sum_j b_{ij}}{\frac{1}{n^2}\sum_{ij} b_{ij}} \quad (2.19)$$

The two kinds of linkage analysis are useful to evaluate the level of intermediate demand or input of an energy source.

2.4.2.2 Estimation results

Figure 2.1 shows the results plotted from the analysis of the forward and backward linkage effects for each energy source calculated from Table 2.3. An analysis of the coefficients of the forward and backward linkages allows the most important sectors in the economy to be identified. The forward linkage effect means the downstream effect (i.e., the effect caused by the sale). The backward linkage effect is a coefficient that evaluates the effect evoked upstream (i.e., the effect from the purchase).

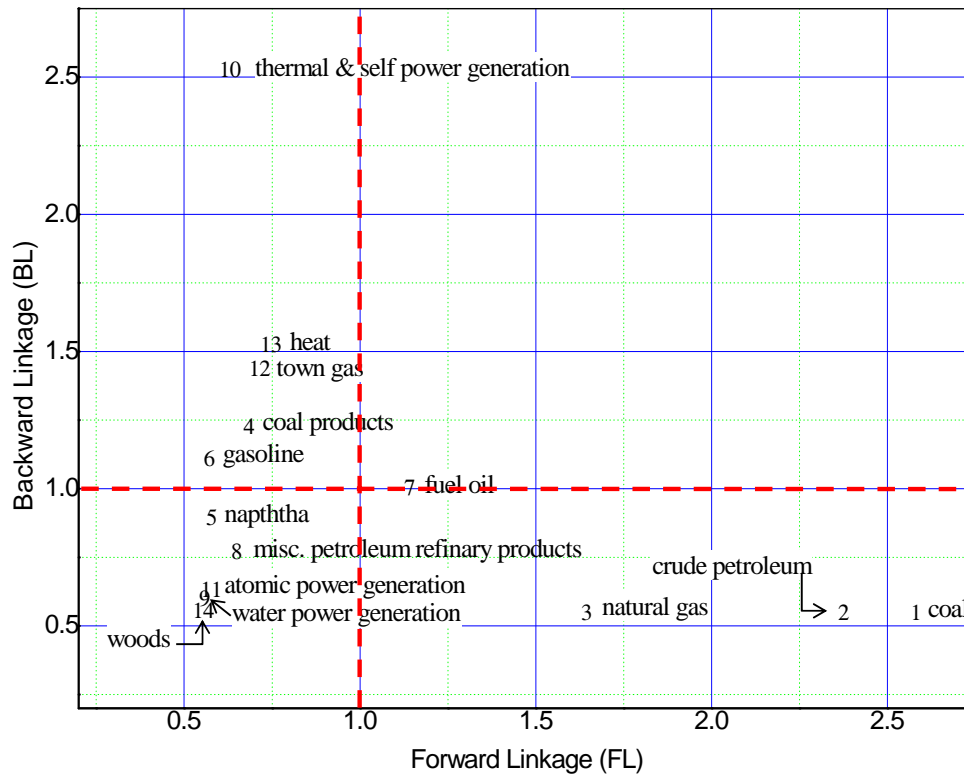


Figure 2.1 Estimation of linkage effect coefficient.

In Figure 2.1, it can be observed that the linkage coefficients are plotted as "1," which is the average of 2 coefficients depending on the energy source. The primary energy in sectors #1, 2, and 3 shows that the forward linkage coefficient is large and the backward linkage coefficient is small. On the contrary, sectors #4, 6, 10, 12, and 13 belong in the region of small forward linkage coefficient but large backward linkage coefficient. Both coefficients are smaller in sectors #5, 8, 9, 11, and 14; whereas both of the coefficients are relatively large in only one sector, #-7.

According to Eqs. (2.18) and (2.19), the forward linkage effect is arranged in the following order:

1. sector-1 (Coal, 2.581)	8. sector-8 (Misc. petroleum refinery products, 0.648)
2. sector-2 (Crude petroleum, 2.375)	9. sector-10 (Thermal & self-power generation, 0.630)
3. sector-3 (Natural gas, 1.644)	10. sector-5 (Naphtha, 0.578)
4. sector-7 (Fuel oil, 1.141)	11. sector-11 (Atomic power generation, 0.577)
5. sector-13 (Heat, 0.747)	12. sector-6 (Gasoline, 0.570)
6. sector-12 (Town gas, 0.715)	13. sector-9 (Water power generation, 0.557)
7. sector-4 (Coal products, 0.683)	14. sector-14 (Woods, 0.554)

The backward linkage effect is in the following order:

1. sector-10 (Thermal & self-power generation, 2.531)	8. sector-8 (Misc. petroleum refinery products, 0.778)
2. sector-13 (Heat, 1.532)	9. sector-11 (Atomic power generation, 0.637)
3. sector-12 (Town gas, 1.443)	10. sector-9 (Water power generation, 0.603)
4. sector-4 (Coal products, 1.231)	11. sector-14 (Woods, 0.560)
5. sector-6 (Gasoline, 1.114)	12. sector-1 (Coal, 0.555)
6. sector-7 (Fuel oil, 1.008)	13. sector-2 (Crude petroleum, 0.554)
7. sector-5 (Naphtha, 0.901)	14. sector-3 (Natural gas, 0.554)

That is, the larger forward linkage effect of an energy sector implies that an expansion of its output is more essential to other energy sectors than an equal expansion in other energy's output in terms of supporting productive activity. Similarly, a larger backward linkage effect of an energy sector means that an expansion of its output is more beneficial to other energy sectors than an equal expansion of another energy output in terms of causing other productive activities.

The results from the two effects can be summarized. Energy sources from sectors 1, 3 and 7 in primary energy have larger forward linkage coefficients, as shown in Figure 2.1. This means that the primary energy is provided to other intermediate sectors and has a larger effect on other industries. On the contrary, smaller forward linkage coefficients are shown in most final energies, which are used by the end user, except sector 7. Obviously, the backward linkage coefficients appear lower if the primary energies are directly extracted from nature (e.g., sectors #-1-3), or if there is no intermediate input from the other energy sources, as sectors #-9, 11 and 14 show, then the value is lower along the Y-axis.

2.5 Conclusion

In this study, typical processes for both a conventional IO approach and an E-IO approach having hybrid units were compared. The convertibility of these approaches was demonstrated using an energy model including the monetary unit and energy unit for an IO approach. In addition, the linkage effects of 14 assorted energy sectors were analyzed using the E-IO table.

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Chapter 3. An Analysis of Sectoral Energy and GHG Emission Intensity in Korea: An Energy IO Approach

An estimation of energy and GHG emission intensity caused by energy consumption in Korea: An energy IO approach, *Applied Energy*, 2009;86: pp1902-1914

In this chapter, a 96×96 hybrid energy input–output (E-IO) table is constructed by using energy units for each energy sector from the 2000 Korean IO table developed by the BOK in 2003. By using this E-IO table, the amount of energy intensities and GHG emission intensities, caused by energy use, are estimated for each sector.

3.1 Introduction

Korea must prepare to the era of post-Kyoto Protocol paradigm. According to the OECD/International Energy Agency (IEA) [1], the CO₂ emissions in Korea caused by energy consumption has reduced from 462.10 million ton of CO₂ (Mt-CO₂) in 2004 to 448.91 Mt-CO₂ in 2005. However, Korea is still ranked 10th in the world for its greenhouse gas (GHG) emissions caused by energy use. Therefore, it is necessary to reduce GHG emissions from the energy sector in Korea.

There is an urgent need for the development of a quantitative model that can reliably establish a relationship between economic activity and energy consumption/environmental load. A reliable econometric model should be developed for various applications. Such a model can be used for reorganization of the industrial structure or energy conservation and for policymaking. The results obtained with such a model can assist in the understanding of the structure of national energy use and the dynamics of GHG emissions. In addition, such a model will help to reduce unnecessary trial-and-error implementations of energy and environmental policies by analyzing the effect of a mandatory reduction in GHG emission on the country's economy.

The global environmental impact of climate change, which is the result of an entire life cycle of a technology, is regarded as a more urgent international issue than the local or regional environment impact of climate change; the impact is evaluated in the technology use stage. Therefore, the proposed model should be able to evaluate the environmental loads of products and services associated with economic sectors including direct and indirect energy use.

In the analysis of energy and GHG emissions, applicable methodologies need to satisfy a prerequisite. The requisite is a clear and comprehensive understanding of factors of internal interactions that influence economy, energy, and GHG emissions. In seeking an effective model, the methodologies can be classified into so called bottom-up, top-down, and hybrid models in terms of approaching paths.

Bottom-up analysis provides retails for individual process or enterprise but lack of comprehensiveness; top-down approaches can apply both to represent whole economy or

society and to reflect its sub-sector. Bottom-up models need disaggregated data and aggregate to the lack of comprehensiveness, while top-down models start with aggregated information and disaggregate as far as they can. Systems can be represented based on technology and cost data and description of physical flows in bottom-up approach. On the other hand, the systems can be described based on macro input-output (IO) or econometric analysis and production functions, e.g., linear, fixed proportional, Cobb-Douglas, etc., to determine technology substitution possibilities in top-down approach.

Although different approaches have their own advantages and shortcomings, well-constructed models have been introduced and demonstrated their usefulness. In bottom-up approach, MARKAL(MARKet ALlocation)[2] and MESSAGE(Model for Energy Supply Strategy Alternatives and their General Environmental Impact)[3] are examples and HERMES(Harmonized European Research for Macrosectoral and Energy Systems)[4], MIDAS(MIXed DATA-frequency Sampling)[5], and computable general equilibrium(CGE)[6] applications, such as GREEN(GeneRal Equilibrium ENvironment)[7] and Jorgenson-Wilcoxon models[8], are noticeable in top-down. While ETA-MACRO[9], MESSAGE-MACRO[10], MARKAL-MACRO[11], and HERMES-MIDAS[12] are prominent in mixed or hybrid model.

In this study, the top-down approach (IO analysis) is applied to quantify the relations of economy, energy, and GHG emissions in detail and to get comprehensive messages for energy and environment in Korea

It is recognized that the IO analysis has unavoidable limitations. The latent limitations of the IO table used in this analysis are as follows.

- price distortion at the process of unit conversion,
- aggregation error in composing a sector, and
- missing necessary product or service in the candidate sector.

Despite the limitations in the conventional IO approach, an IO analysis with the E-IO table can be successfully used in energy and environmental analysis to produce reliable results.

This is because in an E-IO table,

- the types of energy source and the tariff structure are simple;
- each energy source has a large volume in both trading and GHG emission amount;
- the dynamics of GHG emission is simple; and
- all economic sectors consume energy use.

Hybrid IO analyses were performed by the following researchers.

- Miller and Blair [25] authored a well-organized textbook on E-IO analysis.
- Kim [26] constructed an E-IO table for coal, petroleum, gas, and electric power by using IO tables pertaining to the years 1985, 1990, and 1995 and studied the relationship between the energy input and CO₂ emissions from 18 non-energy sectors.
- Choi and Lee [27] analyzed the energy consumption of 28 non-energy sectors that used 5 primary energy sources and 11 final energy sources. Through this analysis, they constructed a hybrid IO table of CO₂ emission and determined the amount of CO₂ emitted by Korea's goods export sector.

When an energy and environmental analysis performed by using a hybrid IO table produces a transactions table, the monetary values pertaining to the energy sectors are substituted with physical units. Thus, hybrid IO analysis helps to eliminate the effect of price distortion on the results and makes the analysis of the implications of the results easy.

One of the objectives of this study is to determine the intensities of energy use and GHG emissions associated with energy use and to identify the behavior of the intensities in Korea through a hybrid E-IO table with higher sectoral resolution. By using an IO table developed by the BOK [28], we created a hybrid E-IO table that consisted of 14 energy sectors and 82 non-energy sectors of the Korean economy. The E-IO analysis performed in this study is different from those performed in previous studies conducted in Korea; in our study, 96 sectors were considered and the number of GHG species was expanded to include CO₂, GH₄, and N₂O in order to provide a more reliable policy recommendation. The results of our study will enable energy policy planners to understand the co-relationship between national economic activity, energy use, and GHG emissions on sectoral basis.

3.2 Construction of the E-IO table

3.2.1 Composition of the E-IO table

An E-IO table is constructed by using the IO table of 2000 developed by the BOK in 2003 [28]. In the E-IO table, energy sectors are expressed in terms of physical units, i.e., tons of oil equivalent (TOE); on the other hand, non-energy sectors are expressed in terms of monetary units, i.e., Korean Won (KRW), as in the case of a conventional IO table. Hence, each column of the table contains values with different units, i.e., TOE for energy sectors and KRW for non-energy sectors, while each row contains values with the same units. Therefore, for energy sectors, each row represents the structure of energy transactions between sectors, and the sum of the values in a row equals the total output of the energy sector corresponding to that row. On the other hand, for non-energy sectors, each row represents the transactions structure of the total output of the sector corresponding to that row, as shown in Figure 3.1.

From \ To		Energy group	Non-energy group		Final use group	Total output
			Energy intensive group	Less energy intensive group		
Energy group		E_k	E_k		e_k	F_k
Non-energy group	Energy intensive group	Z_j	Z_j		y_j	x_j
	Less energy intensive group					
Total input			Total input for energy sector (TOE)			
			Total input for non-energy sector (KRW)			

Figure 3.1 Basic structure of an E-IO table.

3.2.2 Sector rearrangement

The 404 industrial sectors considered in the IO table developed by the BOK [28] are consolidated into 96 sectors. These sectors are subdivided into three groups. The first group, the energy group, comprises 14 energy sources, and the other sectors belong to the non-energy group, which is further divided into two subgroups (energy intensive and less energy intensive), as shown in Table 3.1. Detailed information on the sector aggregation was added to the appendix 1.

Table 3.1 Summary of the rearranged sectors

Group	Code & sector name		
Energy group	1-Coal	2-Crude petroleum	3-Natural gas
	4-Coal products	5-Naphtha	6-Gasoline
	7-Fuel oil	8-Misc. Petroleum refinery products	9-Hydropower generation
	10-Thermal-, self-power generation	11-Atomic-power generation	12-Town gas
	13-Heat	14-Wood	
	15-Crops-p	16-Fishery products	17-Metallic minerals
	18-Nonmetallic minerals	19-Sugar, starches	20-Fiber yarn
	21-Fiber fabrics-p	22-Wood, wooden products-p	23-Pulp, paper-p
	24-Organic basic chemical products	25-Inorganic basic chemical products	26-Synthetic resins, synthetic rubber-p
	27-Chemical fibers	28-Fertilizers, agricultural chemicals-p	29-Other chemical products
	30-Glass products	31-Pottery, clay products	32-Cement, concrete products
	33-Other nonmetallic mineral products	34-Pig iron, crude steel	35-Primary iron, steel products
	36-Nonferrous metal ingots, primary nonferrous metal products-p	37-Fabricated metal products-p	38-Machinery, equipment of general purpose-p
	39-Wholesale, retail trade	40- Restaurants, drinking establishments, hotels, other lodging places	41-Transportation, warehousing-p
Non- energy group	42-Public administration, defense	43-Gas, water supply	44-Medical, health services, social security-p
	45-Other services-p		
	46-Crops-p	47-Livestock breeding	48-Forestry products
	49-Meat, dairy products	50-Processed seafood products	51-Polished grains, flour, milled cereals
	52-Bakery, confectionery products, noodles	53-Seasonings, fats, oils	54-Canned or cured fruits, vegetables, misc. food preparations
	55-Beverages	56-Prepared livestock feeds	57-Tobacco products
	58-Fiber yarn-p	59-Apparel, accessories	60-Other fabricated textile products
	61-Leather, fur products	62-Wood, wooden products-p	63-Pulp, paper-p
	64-Printing, publishing, reproduction of recorded media	65-Synthetic resins, synthetic rubber-p	66-Fertilizers, agricultural chemicals-p,
	67-Drugs, cosmetics, soap	68-Plastic products	69-Rubber products
	70-Nonferrous metal ingots, primary nonferrous metal products-p	71-Fabricated metal products-p	72-Machinery, equipment of general purpose-p
	73-Machinery, specialized equipment	74-Electronic machinery, equipment, supplies	75-Electronic components, accessories
	76-Radio, television, communications equipment	77-Computers, office equipment	78-Household electrical appliances
	79-Precision instruments	80-Motor vehicles	81-Ship building, repairing
	82-Other transportation equipment	83-Furniture	84-Other manufacturing products
	85-Building construction, repair	86-Civil engineering	87-Transportation, warehousing-p
	88-Communications, broadcasting	89-Finance, insurance	90-Real estate agencies, rental services
	91-Business services	92-Educational, research services	93-Medical, health services, social security
	94-Culture, recreational services	95-Other services,	96-Nonclassifiable activities

Remarks: The name of a sector followed by the suffix "-p" refers to a sector that has been partially extracted from one large sector in the BOK IO table

3.2.3 Treatment of energy data

In general, the hybrid IO approach is accurate because it uses the national average price of energy source [28] when the variation in the price of the energy source is small across sectors. However, when the variation in the price of energy source across sectors is high, the accuracy decreases. Each energy source follows the law of one price except electric power, which varies from consumer group in Korea [29].

In this study, sectors with similar energy consumption patterns were grouped together in order to compensate for this weakness in the analysis. In order to examine the validity of our estimated energy consumption data (E-IO case), we compared it with the primary energy consumption data obtained from the national energy census performed by KEEI [29].

Table 3.2 Comparison of primary energy consumption (kTOE)

Energy source	E-IO	KEEI	E-IO/KEEI (%)
Coal	43,896	42,911	102
Crude petroleum	121,901	100,279	122
Natural gas	19,811	18,924	105
Hydropower	487	1,402	35
Thermal & self-power	14,473	32,349	45
Atomic power	9,378	27,241	34

Table 3.2 shows that the values obtained from E-IO analysis and those introduced at KEEI are not always similar. The main reasons for these differences in values are as follows.

First, the methods used to obtain these values differ fundamentally in terms of accounts aggregation. The KEEI energy balance data were eliminated data on energy transformation, international bunkers, and stock change. Of which international bunkers include whole foreign flag overseas vessels and aircrafts refueled at Korea. For example, as can be seen in Table 3.2, the total supply (demand) of crude petroleum calculated using the E-IO table is 121,901 kTOE (10^3 TOE), which is 22% greater than the primary energy consumption reported by KEEI. This discrepancy can be attributed to the following additional accounts that are considered in the "E-IO case" but excluded by the KEEI.

- electric generation, district heating, and gas manufacturing: 6,684 kTOE
- international bunkers: 7,163 kTOE
- statistic difference: 2,308 kTOE
- imports difference between BOK and energy balance sheet: 3,229 kTOE

When these accounts were not considered in the E-IO analysis, the total primary energy consumption of crude petroleum decreased from 121,901 kTOE to 102,517 kTOE, which is comparable to the value obtained by KEEI.

Secondly, the values pertaining to thermal & self-power, hydropower and atomic power generation differ considerably between these two methods. In the study conducted by KEEI, the primary energy consumption was calculated by considering the thermal efficiency, unlike in the case of our E-IO analysis. The differences in the values listed in Table 3.2 for thermal &

self-power, hydropower and atomic power generation (45%, 35% and 34%, respectively) are close to the differences in the thermal efficiencies at those energy transformations. In fact, the efficiency of the thermal & self-power plant in 2000 was 39.45%. Thermal efficiency was not considered in our analysis because there is no direct GHG emission from hydropower and atomic power generations. It has already been considered in the calculation of primary energy.

3.2.4 The producibility condition

In the Leontief inverse matrix of the E-IO table used in this study, the total outputs must satisfy the condition of non-negativity in terms of economic producibility. This condition can be checked with satisfaction of the Hawkins and Simon (H-S) [30] condition.

Miller and Blair [25] introduced the H-S conditions in a Leontief model to obtain a nonnegative solution, such that a non-negative output is the result of a given nonnegative final demand. This condition was verified in our E-IO table by performing the following steps.

- The following conditions must be satisfied for the $(\mathbf{I}-\mathbf{A})$ coefficients matrix to satisfy the H-S conditions (here, \mathbf{I} is an identity matrix and \mathbf{A} is an input coefficient matrix). First, all the diagonal elements in the matrix must be positive, and all the non-diagonal elements must be non-positive. The E-IO table constructed in this study satisfies both conditions.
- Secondly, the determinants of all leading principle sub-matrices (minors) in the coefficients matrix $(\mathbf{I}-\mathbf{A})$ of each year were positive; This implies that all the $(\mathbf{I}-\mathbf{A})$ matrices calculated in this study satisfy the H-S condition.

Therefore, the Leontief inverse matrix was assumed to satisfy the H-S conditions.

3.2.5 Prevention of double count error

In order to perform an E-IO analysis, it is important to understand the concept of energy flow accurately. There are three representative types of energy use in economic sectors. They involve different energy consumption processes and result in different GHG emissions, as shown in Figure 3.2.

Type 1 is the simplest case of energy use in the final demand sector, which comprises a private sector (P_v) as well as a government one (G_v) in the IO table constructed by BOK (2003). In type 1, the sector acquires the required amount of energy from the energy source (e) and emits GHGs directly after consuming this energy.

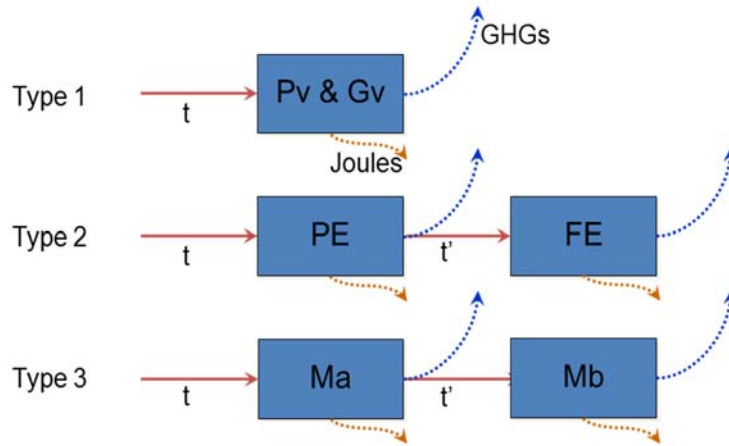


Figure 3.2 Three types of energy use and GHG emission in economic sectors.

Type 2 pertains to the energy group. Fourteen energy sources were consolidated from mixed sectors such as the following: (1) coal, which can provide primary energy (*PE*) to be used directly by the end users; (2) crude petroleum, which can be converted into a secondary energy (*SE*) source like naphtha and gasoline; and (3) power generation, in which *PE* or *SE* from other sources is used as fuel to generate final energy (*FE*) in the form of electricity. At this stage, we need to ascertain whether the total input energy (t) is used to acquire the energy or as raw material (t') for the next step. This will prevent an energy source from being considered twice when calculating energy and GHG emissions intensities.

Lastly, type 3 represents the input energy use in non-energy sectors. The input energy sources in non-energy manufacturing sectors (*Ma*) are mainly used for combustion; however, in some cases, they are used for downstream manufacture (*Mb*) such as in the case of petrochemical products or pavement materials. This study considers the input ratios of asphalt and naphtha in the civil engineering and petrochemical sectors, respectively. The input percentages of coal, naphtha, and miscellaneous petroleum refinery products to raw materials were 2.5%, 75%, and 76%, respectively.

3.3 E-IO analysis

An estimation of energy consumption and intensity of GHG emission associated with energy use by using the E-IO table produced the results that were dissimilar to those obtained by using the conventional IO table. The E-IO analysis is generally carried out in three steps, as shown in Figure 3.3. The monetary transaction data and price data (represented dotted circles) for each energy source were obtained from Korea's conventional IO tables. After simple calculations with some data at the first box, an E-IO table containing values with two different types of units, so called hybrid-units type E-IO table, is constructed. In this study, the hybrid-units type E-IO table which was developed by Shim [31] was used to estimate the energy intensities and GHG emission intensities for three types of element for 96 economic

sectors in Korea. Then, the E-IO analysis is performed to explain the co-relationship among an economic activity, energy use, and GHG emissions.

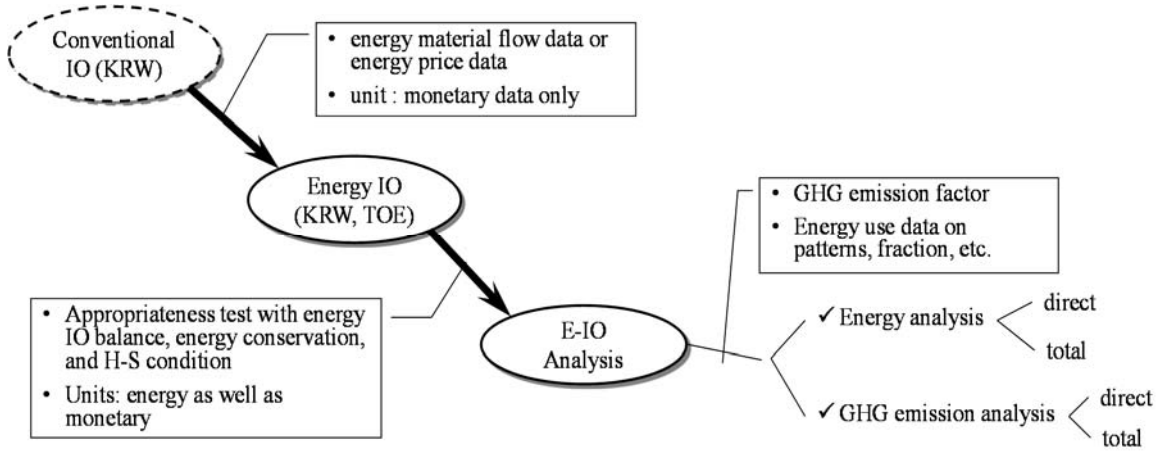


Figure 3.3 General procedure of E-IO analysis.

3.3.1 Procedure for estimating energy intensity

In an E-IO table, energy flow is expressed in physical units such as TOE or other convenient energy units, while non-energy flows are expressed in monetary units.

In order to obtain all the values in the table in physical units, the total monetary requirement is computed by using a conventional IO table and then to convert these values to TOE using unit prices of energy outputs. The basic procedure of performing an E-IO analysis was introduced by Miller and Blair [25]

In order to estimate the energy and environment inventories associated with economic activities by using the E-IO table in monetary and physical units, the following additional definitions of matrices and vectors are needed as described in chapter 2.

\mathbf{Z}^* is the new transactions matrix of dimensions $n \times n$ obtained by changing k energy sectors in a conventional IO table from monetary units to energy units row-wise. Thus, this matrix is comprised of the original inter-sector transactions matrix \mathbf{Z} in the non-energy sectors and an energy flow matrix \mathbf{E} in the energy sectors. n is the number of sectors ($n = 96$ and $k = 14$ in this study).

\mathbf{X}^* and \mathbf{Y}^* are $n \times 1$ vectors that represent the total output and the final demand, respectively. These two vectors contain elements with both monetary and energy units. Hence \mathbf{X} and \mathbf{Y} mean total output and final demand for non-energy rows respectively. \mathbf{e} shows final energy demand in energy rows.

\mathbf{F}^* is an artificial $n \times 1$ vector that is used to isolate energy rows during matrix manipulation. \mathbf{F}^* consists of zero vector for non-energy rows and \mathbf{F} representing total energy consumption for energy rows.

These matrices are defined as follows

$$Z_i^* = \begin{cases} E_k, & \text{for energy rows} \\ Z_j, & \text{for non – energy rows} \end{cases} \quad (3.1)$$

$$X_i^* = \begin{cases} F_k, & \text{for energy rows} \\ X_j, & \text{for non – energy rows} \end{cases} \quad (3.2)$$

$$Y_i^* = \begin{cases} e_k, & \text{for energy rows} \\ y_j, & \text{for non – energy rows} \end{cases} \quad (3.3)$$

$$F_i^* = \begin{cases} F_k, & \text{for energy rows} \\ 0, & \text{for non – energy rows} \end{cases} \quad (3.4)$$

\mathbf{E} is a $k \times n$ matrix that represents energy flows. \mathbf{E}_y and \mathbf{T} are $k \times 1$ vectors expressed in terms of physical units, and they designate the energy consumed by a final demand and the total energy consumption in the economy, respectively. Hence, the total amount of energy consumed (and produced) by the economy is the sum of the energy (of each type represented by the rows in \mathbf{E}) consumed by intermediate sectors and that consumed by the final demand. This can be expressed as follows:

$$\mathbf{E} + \mathbf{E}_y = \mathbf{T} \quad (3.5)$$

When this definition is used, the corresponding matrices $\mathbf{A}^* = \mathbf{Z}^*(\widehat{\mathbf{X}^*})^{-1}$ and $(\mathbf{I} - \mathbf{A}^*)^{-1}$ can be calculated easily. Hat (^) over a capital letter indicates that the elements composing the vector have been converted to a diagonal of a corresponding matrix. However, these matrices have characteristics different from those of the traditional Leontief matrices. For example, the input coefficient matrix \mathbf{A}^* , which represents direct requirements, and the inverse coefficient matrix $(\mathbf{I} - \mathbf{A}^*)^{-1}$, which represents total requirements, have different elements because they are combined with a matrix having hybrid units.

$$\mathbf{Z}^* = \begin{bmatrix} TOE & TOE \\ KRW & KRW \end{bmatrix}; \quad \mathbf{X}^* = \begin{bmatrix} TOE \\ KRW \end{bmatrix}; \quad \mathbf{Y}^* = \begin{bmatrix} TOE \\ KRW \end{bmatrix}; \quad \mathbf{F}^* = \begin{bmatrix} TOE \\ 0 \end{bmatrix}$$

An input coefficient matrix is composed of four elements with heterogeneous characteristics, as shown in Eq. (3.6).

$$\mathbf{A}^* = \mathbf{Z}^* (\widehat{\mathbf{X}^*})^{-1} = \begin{bmatrix} toe/toe & toe/\$ \\ \$/toe & \$/\$ \end{bmatrix} \quad (3.6)$$

$(\mathbf{I} - \mathbf{A}^*)^{-1}$ has the same characteristics as \mathbf{A}^* shown in Eq. (3.6). Both matrices are of dimensions $n \times n$.

By using the \mathbf{A}^* and $(\mathbf{I}-\mathbf{A}^*)^{-1}$ matrices, the direct energy coefficients (\mathbf{EI}_δ) and total or embodied energy coefficients (\mathbf{EI}_α) can be calculated by the following equations.

$$\mathbf{EI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{A}^* \quad (3.7)$$

$$\mathbf{EI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} (\mathbf{I} - \mathbf{A}^*)^{-1} \quad (3.8)$$

By using Eqs. (3.7) and (3.8), the rows pertaining to 14 energy sectors are isolated from the \mathbf{A}^* and $(\mathbf{I}-\mathbf{A}^*)^{-1}$ matrices shown in Eq. (3.6). The reasons for isolating these rows are as follows: 1) the results of the analysis can be explained systematically; and 2) the difference in the nature of the results obtained for the 14 energy sectors and that of the results obtained for the 2 groups comprising non-energy sectors. This implies that the denominators in the case of the energy sectors and the non-energy sectors are in energy units (TOE) and monetary units (KRW), respectively.

In the case of the energy group, the values are expressed in terms of TOE/TOE, which is the energy ratio of the 14 energy sources that are components of this group. However, in the case of the non-energy group, the values are expressed in terms of TOE/KRW, which is the energy intensity, i.e., energy use per unit production. Hereafter, each sector will be represented by its sector number for the sake of convenience.

3.3.2 Estimation of the GHG emissions

In this study, we confine our focus to CO₂, CH₄, and N₂O emissions only, mainly because they are listed in the Intergovernmental Panel on Climate Change (IPCC) (revised in 1996) [32] as having a direct causative role in global warming. For the assessment of the amount of GHG emissions caused by energy consumption alone, the emission factors recommended in the IPCC Guidelines [32] were used. However, these factors were partly modified in order to reflect the conditions in Korea. Two modifications were performed according to the recommendations of the IPCC. Firstly, the fraction of carbon stored and fraction of carbon oxidized in the case of each fuel was ascertained in order to study the differences in the consumption pattern of the 14 energy sources. Secondly, since the energy sources were classified into 14 sectors, the emission factors were modified by a weighted average of included energy sources. The modified CO₂ emission coefficients for each fuel type are shown in Table 3.3. The emission coefficients of CH₄ and N₂O pertaining to each type of fuel recommended in the IPCC guidelines were not modified. The GWPs (Global Warming Potentials) of CH₄ and N₂O emissions were set at 21 and 310, respectively, for calculation of the CO₂ equivalent (CO₂-eq.) emissions.

In 2007, the IPCC [33] issued an updated guideline report on emission coefficients in “IPCC 2006 Guidelines for National Greenhouse Gas Inventories,” which was not formally adopted for formulating national policies. OECD/IEA [34] still uses the IPCC Guidelines [32], which were not adopted in Korea. Nevertheless, the guidelines provide consistent information on past GHG emission statistics in Korea. On the basis of these backgrounds, we will use the emission coefficients prescribed by the IPCC Guidelines [32].

Table 3.3 Modified GHG emission factors for each energy source (t-CO₂-eq./TOE)

Energy source	Emission factor	Included fuels
Coal	3.732	
Crude petroleum	3.009	
Natural gas	2.298	
Coal products	4.077	BKB and patent fuel, coke, coal briquette, etc.
Naphtha	0.752	
Gasoline	2.842	Jet oil A-1, P-4
Fuel oil	2.790	Kerosene, diesel, bunker A~C, and LPG
Misc. petroleum refinery products	0.773	Asphalt, lubricant, paraffin wax, etc.
Hydropower generation	0	
Thermal and self-power generation	0	
Atomic power generation	0	
Town gas	2.334	Naphtha, propane, LNG
Heat	0	LNG, LSWR, bunker C, and waste burning
Wood	1.178	

Remarks: Unlike the common sense of a thermal and self-power generation with zero emission factor, this study is based on the consumer use phase in calculation.

The direct emission intensity of GHG (\mathbf{GI}_δ) and the total intensity (\mathbf{GI}_α) of the intermediate transaction sectors by energy use are calculated using Eqs. (3.9) and (3.10), respectively. The dimension of the above matrices is $k \times n$.

$$\mathbf{GI}_\delta = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1} \mathbf{M} \mathbf{A}^* \quad (3.9)$$

$$\mathbf{GI}_\alpha = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1} \mathbf{M}(\mathbf{I} - \mathbf{A}^*)^{-1} \quad (3.10)$$

where \mathbf{M} is a symmetric matrix with dimensions $n \times n$, and it designates the emission factors of specific GHGs (e.g., CO₂, CH₄, N₂O) by type of energy resource ($k = 1, 2, \dots, 14$ in Table 3.3). The unit is measured from the amount of GHG emission per production price.

We also calculated the direct GHG emissions intensity of the final demand sector, which includes a private sector and a government sector.

3.4 Results: Creation of inventory database

3.4.1 Energy intensity analysis

3.4.1.1 Energy intensity by industrial sector

Two energy intensities were estimated: the direct energy intensity calculated by using the input or technical coefficients matrix and the embodied energy intensity calculated from the

Leontief inverse coefficients matrix. The indirect energy intensity for each sector can be acquired by subtracting the direct energy intensity from the total energy intensity.

The average values of the direct and total energy intensities were found to be 0.132 and 0.640 (TOE/M-KRW), respectively. In terms of direct energy use, sectors with high energy intensities in the energy group, the energy intensive group and the less energy intensive groups were sectors 10 (thermal and self-power generation; 2.440 TOE/M-KRW), 24 (organic basic chemical products; 1.137 TOE/M-KRW), and 69 (rubber products; 0.092 TOE/M-KRW), respectively. The sectors with high embodied energy intensities in the energy group, the energy intensive group and the less energy intensive groups were sectors 10 (4.571 TOE/M-KRW), 24 (2.607 TOE/M-KRW), and 65 (synthetic resins and synthetic rubber; 1.559 TOE/M-KRW), respectively. In both cases, the sectors with the highest direct energy intensity were almost the same, as can be seen in Table 3.4.

Table 3.4 The top three sectors in direct and total energy intensities in each group (TOE/M-KRW)

		Direct energy use		Total energy use	
		Sector	Value	Sector	Value
Energy group		10-Thermal and self-power generation	2.440	10-Thermal and self-power generation	4.571
		12-Town gas	1.560	13-Heat	2.767
		4-Coal products	1.203	4-Coal products	2.223
Non-energy group	Energy intensive group	24-Organic basic chemical products	1.137	24-Organic basic chemical products	2.607
		34-Pig iron and crude steel	0.651	34-Pig iron and crude steel	2.481
		33-Other nonmetallic mineral products	0.649	27-Chemical fibers	1.759
	Less energy intensive group	69-Rubber products	0.092	65-Synthetic resins and synthetic rubber-p	1.559
		68-Plastic products	0.072	66-Fertilizers and agricultural chemicals-p	1.217
		53-Seasonings,fats and oils	0.066	68-Plastic products	0.848

Except primary energy sources, sectors 10 (thermal and self-power generation), 33 (other nonmetallic mineral products) and 87 (transportation, warehousing-p) were characterized by the largest ratios of direct to total energy intensity in each group, 53.4%, 51.9% and 35.1%, respectively, as shown in Figure 3.4. This ratio close to 100% means that direct intensity accounted for almost all of the total intensity because of small indirect intensity. In other words, latent impacts of a unit change in final demand can be observed from the direct changes in the sector easily. In contrast, the ratio close to 0% means that contribution of indirect energy intensity is quite significant.

The effect of the increase in direct consumption is extremely smaller than that of the increase in total energy consumption in sectors 35 (primary iron and steel product) and 77 (computer and office equipment), which had very small consumption ratios of 6.3% and 2.8%, respectively. The consumption ratios of sectors 2 (crude petroleum), 3 (natural gas), and 14 (wood) in the energy group were 0% because the raw materials in these sectors were imported completely from overseas.

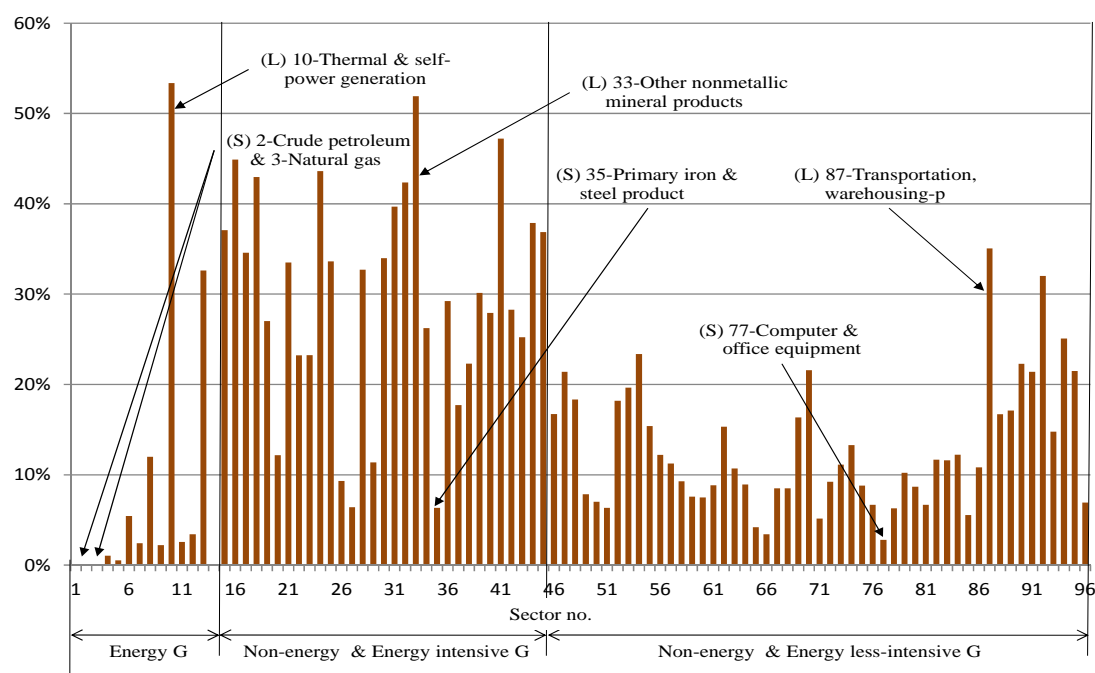


Figure 3.4 Ratio of direct to total energy intensity.

The ratio representing direct to total is important. Within each group, sector with the largest and the smallest ratio is marked (L) and (S) respectively. National energy policy maker should pay more attention to the behavior of (S) rather than (L). Because, even smaller ratio sectors do not reveal their energy consumption in conventional analysis but the sectors induce much more energy consumption of other sectors than larger one.

3.4.1.2 Energy intensity by energy source

The direct energy intensity and embodied energy intensity for each energy source in each group are shown in Figures 3.5 and 3.6, respectively

In the energy group, the consumption of coal (34.8%) and crude petroleum (27.3%) was the highest in terms of direct energy use; the consumption of coal (18.4%), crude petroleum (17.0%), and natural gas (11.7%) was the highest in terms of total energy use. In the energy-intensive group, the consumption of fuel oil (37.5%) and naphtha (16.5%) accounted for 54.0% of direct energy use, while the consumption of crude petroleum (24.6%) and fuel oil (18.3%) accounted for 43% of total energy use. Lastly, in the less energy-intensive group, the consumption of fuel oil (55.0%) and thermal and self-power generation (12.5%) accounted for 67.4% of direct energy use, and the consumption of crude petroleum (28.0%) and fuel oil (20.0%) contributed to 48.1% of total energy use.

In terms of direct energy use, the most frequently used energy source was found to be coal for the energy group and fuel oil for the non-energy group. On the other hand, there seems to be no predominantly used energy source in total energy use; however, the consumption of crude petroleum appears to make a significant contribution to the total energy use.

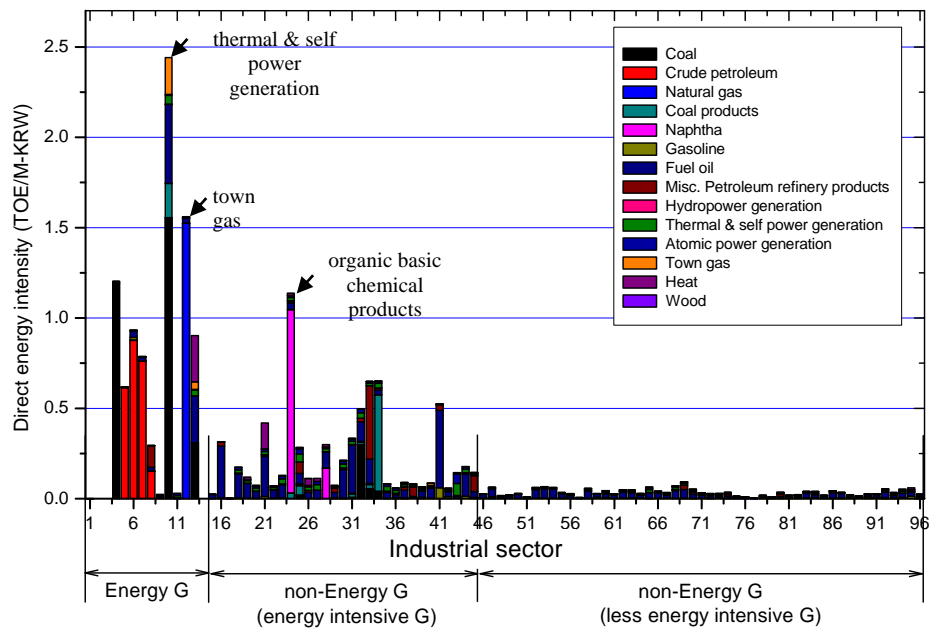


Figure 3.5 Sectoral direct energy intensity by 14 energy sources.

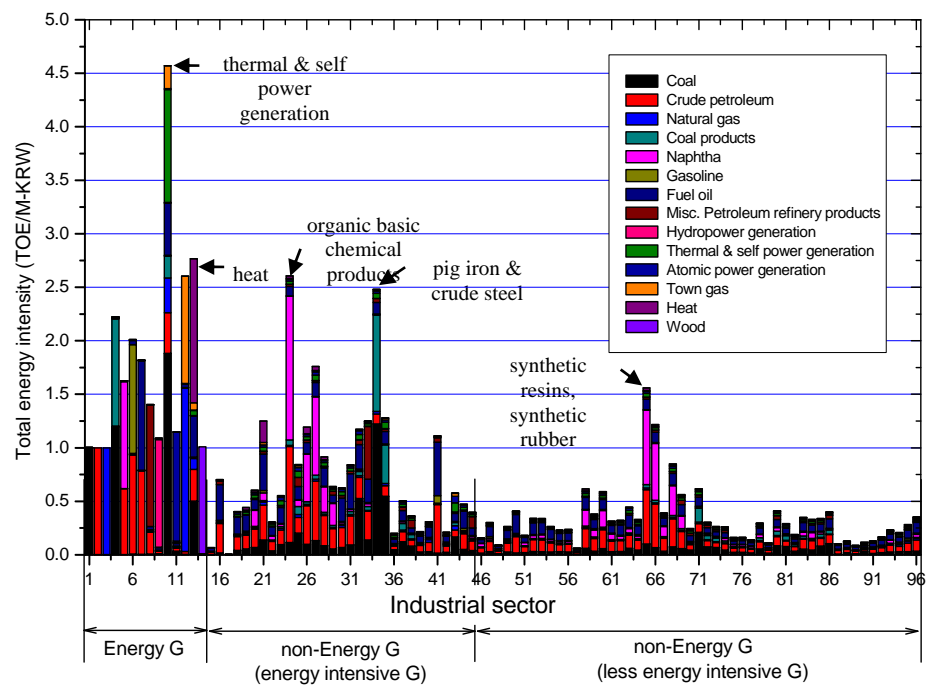


Figure 3.6 Sectoral embodied energy intensity by 14 energy sources.

3.4.2 GHG emission intensity analysis

3.4.2.1 GHG emission intensity by industrial sector

The average ratios of direct GHG emission intensity to total emission intensity for the energy group, energy intensive group, and less energy intensive group were found to be 12.4%, 23.9%, and 10.7%, respectively.

The sectors with the largest direct GHG emission intensities in the energy group, energy intensive group, and less energy intensive group were sectors 10 (thermal and self-power generation; 8.611 t-CO₂-eq./M-KRW), 34 (pig iron and crude steel; 2.518 t-CO₂-eq./M-KRW), and 69 (rubber products; 0.176 t-CO₂-eq./M-KRW), respectively. The sectors with the largest embodied GHG emission in terms of total emission intensity in the energy group, energy intensive group, and less energy intensive group were sectors 10 (thermal and self power generation; 11.717 t-CO₂-eq./M-KRW), 34 (pig iron and crude steel; 9.007 t-CO₂-eq./M-KRW), and 65 (synthetic resins and synthetic rubber-p; 2.955 t-CO₂-eq./M-KRW), respectively, as shown in Figure 3.7.

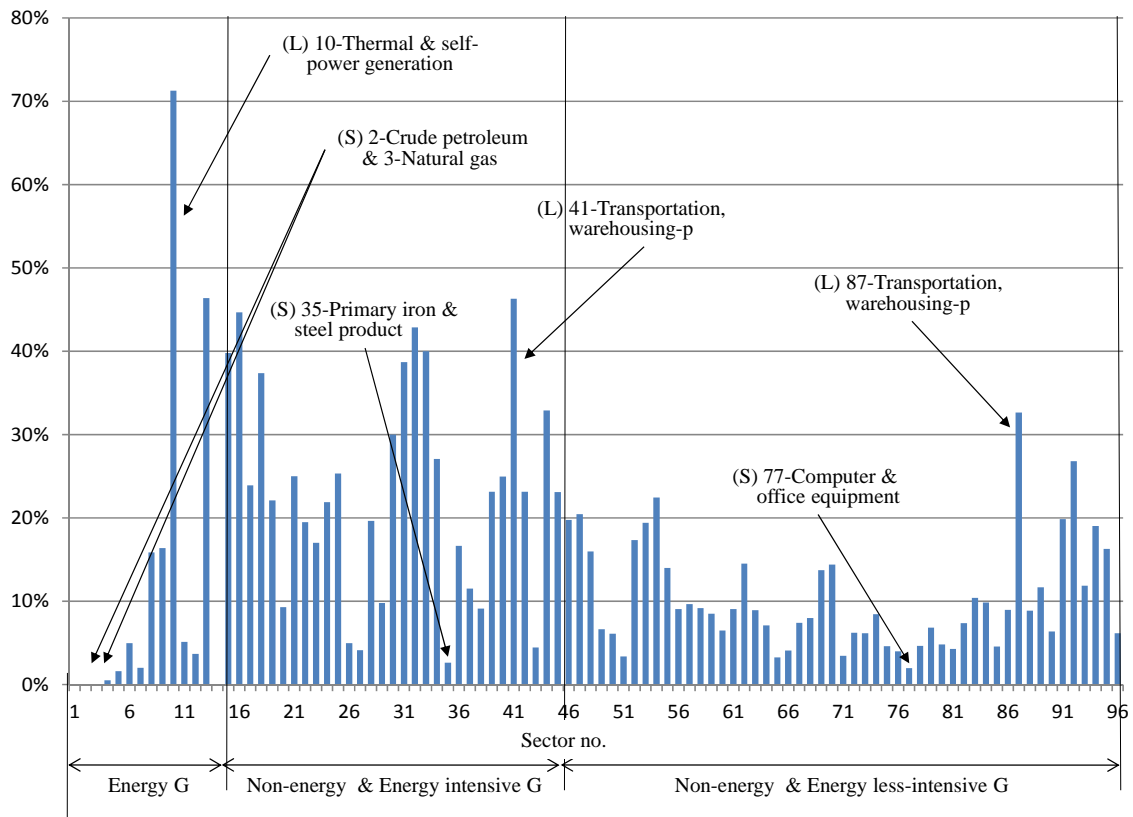


Figure 3.7 Ratio of direct to total GHG emissions intensity.

Figure 3.7 suggests that a policy for GHG emission reduction or control based on only the direct emissions or measurements from the end of pipe would be less effective. Therefore, it is very important to consider total emissions before framing a policy for GHG emission control. Especially considering total emission is more important in the strategic point of view. Because sectors such as sector 35(Primary iron & steel product) in energy intensive group and sector

77(Computer & office equipment) in energy less-intensive group, imply that they induce much more GHG emission than that sectors displayed longer blue bar.

By using the E-IO table, the direct and total GHG emissions caused by energy consumption in Korea in 2000 were found to be 512 Mt-CO₂-eq. and 1,378 Mt-CO₂-eq., respectively. The emissions from the energy group, energy intensive group, less energy intensive group, and final demand group were 61.0%, 22.4%, 0.5%, and 16.1% of the total emission, respectively. Table 3.5 shows direct and total emissions from 3 GHG materials for all groups. Since only the direct emissions can be calculated in the final demand group, indirect emissions are not included in the total emission of this group. The ratios of total to direct emission for the energy group, energy intensive group, and less energy intensive group were 280.9%, 342.6%, and 1,097.1%, respectively.

Table 3.5 Estimation of GHG emissions in 2000

GHG emissions	CO ₂ (kt-CO ₂)		CH ₄ (kt-CH ₄)		N ₂ O (kt-N ₂ O)		Total (kt-CO ₂ -eq.)	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
Energy group	310,749	873,316	6	27	4	10	312,182	876,958
Non-energy groups	116,118	416,433	14	41	2	6	117,036	419,056
Final demand group	81,826	81,826	15	15	0.6	0.6	82,339	82,339
Total	508,693	1,371,575	35	84	7	16	511,556	1,378,352

Remarks: Those in parenthesis under GHG represent their own unit

The values of the GHG emissions estimated in this study were compared with those obtained by KEEI [35] for the energy sector. (The KEEI report is regarded as an official national communication report in Korea.) The CO₂ and N₂O emissions were overestimated by 16% and 137%, respectively, in our study, while CH₄ was underestimated by approximately 19%, as shown in Table 3.6.

The difference was considered to be within acceptable limits because of the following two reasons. Firstly, GHG emission, especially N₂O emission is not yet fully understood in Korea and the national statistical data has great uncertainty. Secondly, the inherent limitations of the IO analysis, such as price distortion in unit conversion, aggregation error in setting sectors up, and missing necessary item in a sector, were found to persist in the E-IO analysis, too.

Table 3.6 Comparison of GHG emissions in 2000 with the National Communication Report

Emissions	Direct			Total		
GHG	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
Unit	kt-CO ₂	t-CH ₄	t-N ₂ O	kt-CO ₂	t-CH ₄	t-N ₂ O
E-IO(2008) (a)	508,693	35,499	6,832	1,371,575	83,564	16,201
Energy sector in National statistic(2003) (b)	438,537	43,714	2,884	NA	NA	NA
Comparison (a/b)	116%	81%	237%			

3.4.2.2 Sectoral GHG emission factor estimation by GHG species

The emission factor EF_j , which is the amount of GHG emission of the sector j per consumed energy, can be calculated by

$$EF_j = \frac{\sum_{i=1}^{14} (E_{i,j} \times M_{i,j})}{\sum_{i=1}^{14} E_{i,j}}, \text{ for } j = 1, 2, 3, \dots, 96 \quad (3.11)$$

where $E_{i,j}$ and $M_{i,j}$ represent energy consumption and the GHG emission factor pertaining to energy source i in sector j , respectively.

Note that the total calculated emission consisted of CO₂, CH₄, and N₂O emissions only.

The results of the analysis showed that the highest CO₂, CH₄, and N₂O emissions were from sectors 10 (thermal and self-power generation; 3.407 t-CO₂/TOE), 13 (heat; 0.116 kg-CH₄/TOE), and 10 (thermal & self-power generation; 0.047 kg-N₂O/TOE), respectively, in the energy group. In the energy intensive group, sectors 34 (pig iron and crude steel; 3.722) and 32 (cement and concrete products; 3.047) had the highest CO₂ emission factors. In contrast, sector 43 (gas and water supply; 0.410) and 24 (organic basic chemical products; 0.895) had the lowest CO₂ emission factors in this group. Further, sectors 41 (transportation and warehousing-p; 0.471) and 15 (crops-p; 0.416) had the highest CH₄ emission factors, while sectors 35 (primary iron and steel products; 0.052) and 43 (gas and water supply; 0.054) had the lowest. Sectors 34 (pig iron & crude steel; 0.053) and 32 (cement & concrete products; 0.044) had the highest N₂O emission factors, whereas sectors 43 (gas and water supply; 0.003) and 35 (primary iron and steel products; 0.014) had the lowest. Finally, in the less energy intensive group, sectors 46 (crops-p; 2.890) and 59 (apparel and accessories; 2.626) had the highest CO₂ emission factors. On the other hand, sectors 90 (real estate agencies and rental; 0.691) and 75 (electronic components and accessories; 1.243) had the lowest CO₂ emission factors. Furthermore, sector 46 (crops-p; 2.073) had a distinctively high CH₄ emission factor, while sectors 51 (polished grains, flour and milled cereals; 0.040) and 75 (electronic components and accessories; 0.057) had low CH₄ emission factors. Sectors 46 (crops-2p; 0.033) and 47

(livestock breeding; 0.029) had the highest N₂O emission factors, and sector 90 (real estate agencies and rental; 0.005) had the lowest N₂O emission factor, as shown in Figure 3.8.

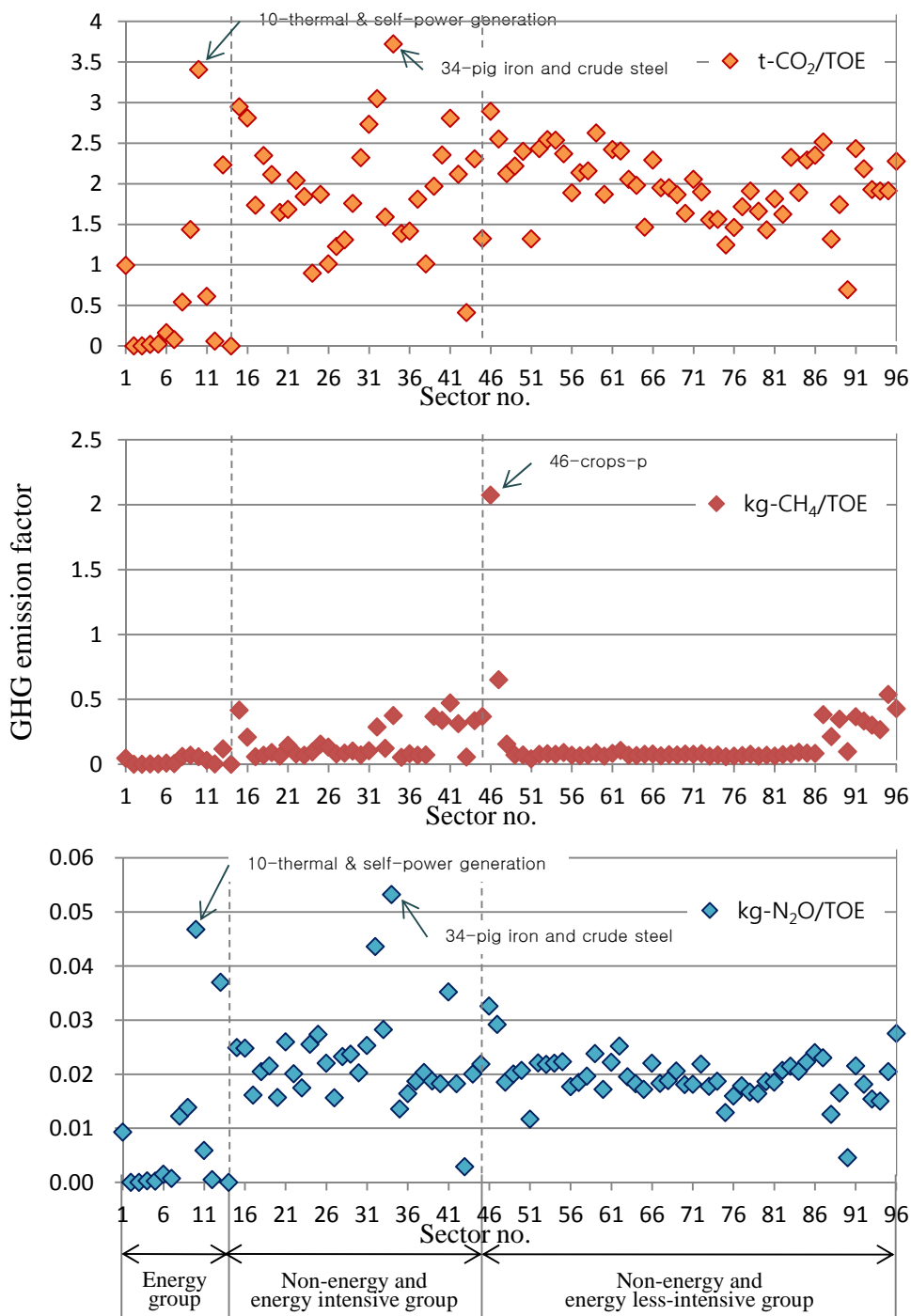


Figure 3.8 GHG emission factors of 96 sectors.

3.4.3 A concise representation of the results

In the case of direct energy use, the average values of direct energy intensity and GHG emission intensity of the 96 economic sectors were 0.186 TOE/M-KRW and 0.315 t-CO₂-eq./M-KRW, respectively. In the case of total energy use, the average values of total (or embodied) energy intensity and GHG emission intensity were estimated to be 0.640 TOE/M-KRW and 1.534 t-CO₂-eq./M-KRW, respectively.

Figures 3.9 and 3.10 show the relationship between energy intensity and GHG emission intensity for direct and total energy use, respectively. In Figures 3.9 and 3.10, the regression lines are plotted and the slopes indicate CO₂ elasticity of energy which is smaller than unity. If a sector is above the regression line in Figure 3.9 (for example, sector 34), its actual CO₂ emission factor will be larger than that predicted by the regression model, and the measures to reduce CO₂ emissions must be taken. Further, the average energy use and GHG emission intensities for all industrial sectors in 2000 are used as the origins of the coordinate system shown in these figures. The energy intensity of a sector that lies to the right of the ordinate axes is higher than the average value. On the other hand, the energy intensity of a sector that lies to the left of the ordinate axes is lower than the average value.

GHG emissions are in proportion to energy use in sectors that are located in quadrants I and III in Figures 3.9 and 3.10. Sectors with lower energy intensities but higher GHG emission intensities than the average are located in quadrant II. Such sectors are typically characterized by industries that use processes that are not eco-friendly in terms of energy use or carry out combustion process on a large scale. On the other hand, sectors with higher energy intensities but with lower GHG emission intensities than the average are located in quadrant IV. The sectors employ low GHG emitting energy use or employ combustion technology but consume much more energy than the other sectors. None of the sectors in non-energy group are located in quadrants II and IV.

Most sectors are located in quadrants I or III. Further, in Figures 3.9 and 3.10, the sectors largely remain in the same quadrants. However, some sectors showed a significant change. For example, sector 35 (primary iron and steel products) that is located in quadrant III in Figure 3.9 is located in quadrant I in Figure 3.10. Since this sector depends heavily upon coal or coal products which owe much energy and CO₂ at the indirect process, the embodied energy pertaining to this sector increases drastically. On the other hand, sectors 9 (hydropower generation) and 11 (atomic power generation) are below the regression line but are located in quadrant III in Figure 3.9 and quadrant IV in Figure 3.10. As these industries indulged in more indirect energy use, they are shifted to the right from quadrant III in Figure 3.9 to quadrant IV in Figure 3.10; further, because of their low dependence on fossil energy sources such as coal, crude petroleum, and coal products, these sectors remain below the horizontal average line for GHG emission intensity in Figure 3.10. The difference in the change of position of sectors 9 (hydropower generation) and 11 (atomic power generation) in Figure 3.10 can be explained by the fact that sector 11 uses more coal than sector 9.

The E-IO analysis provided not only speculative information on the total energy use and GHG emission but also some detailed practical information about each sector.

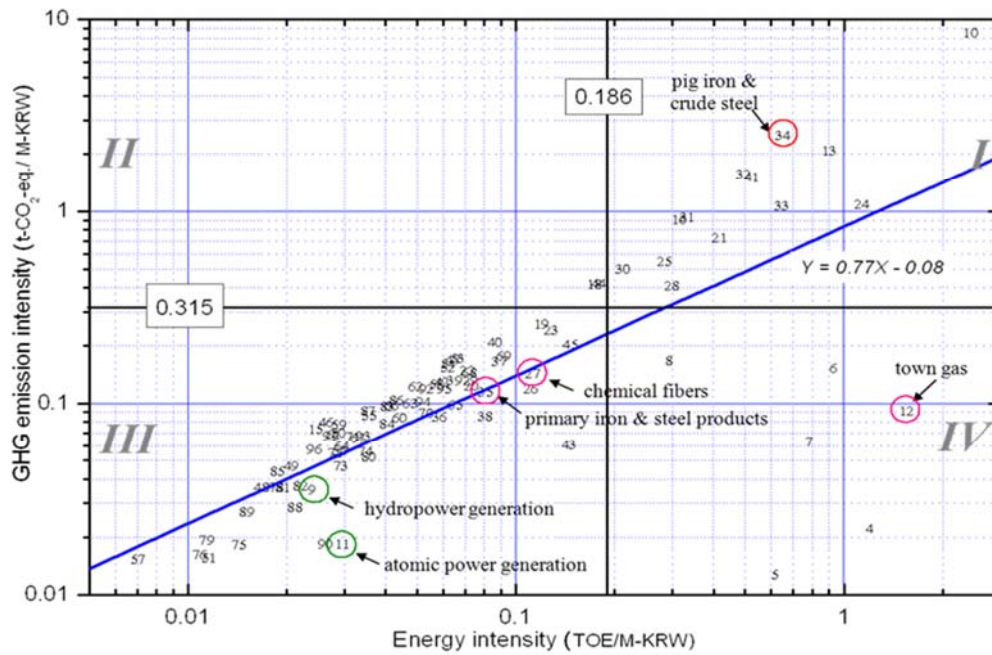


Figure 3.9 Distribution of 96 sectors from direct energy use.

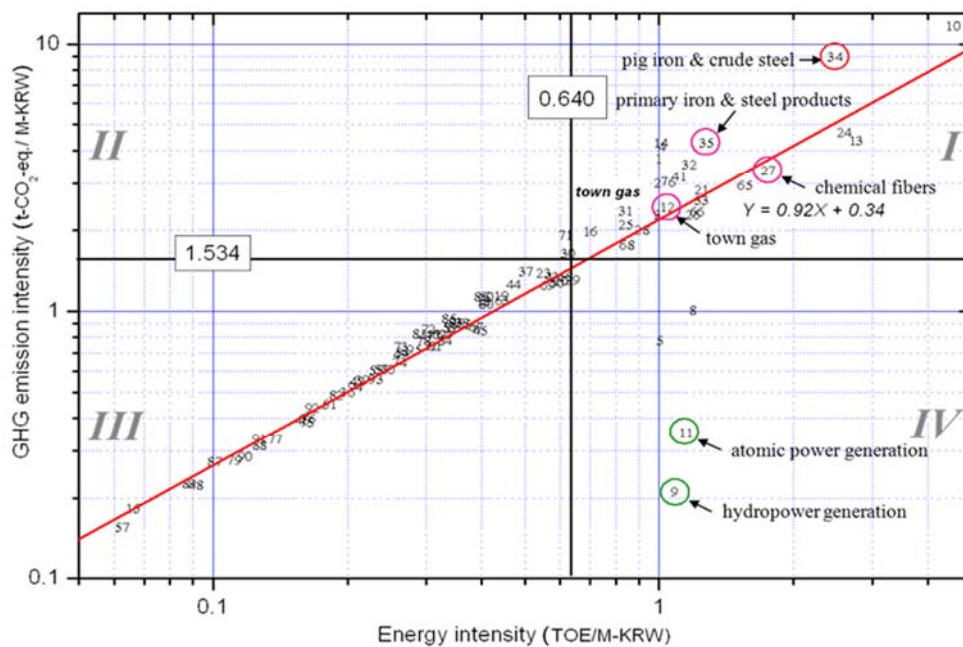


Figure 3.10 Distribution of 96 sectors from embodied energy use.

Korea's efforts to prevent the climate change in energy use are often planned based on the projection of 96 industries, plotted in Figures 3.9 and 3.10, onto the X, Y axis. It means that industrial policies are formulated by analyzing the characteristics of energy or GHG emission in a separate manner. This is equivalent to analyzing the industry in a one-dimensional straight line. However, in order for Korea's energy and environment countermeasure not to slow down the economic activity as well as achieve GHG reduction, both GHG emission and energy use characteristics of 96 industries must be taken into consideration at the same time. Moreover, each industry must be understood in a two-dimensional plane.

3.5 Conclusion

E-IO analysis was performed for 96 aggregated sectors including 14 energy sources and the energy intensities as well as GHG emission intensities of all the sectors were calculated.

We have elucidated the structure of energy use and GHG emission in each industrial sector in Korea. Sectors 27 (chemical fibers) and 35 (primary iron and steel products) were characterized by relatively low levels of both energy use and GHG emission intensity; however, in these sectors the induced effect of energy intensity and GHG emission intensity was observed to be higher than the direct effect. Therefore, sectors similar to sectors 27 and 35 can be regarded as superior to the rest in terms of direct emission intensity but inferior in terms of embodied emission intensity. In the energy group, sectors 9 (hydropower generation) and 11 (atomic power generation) are inferior to the rest of the sectors in terms of embodied energy intensity but are superior in terms of GHG emission intensity. Sector 12 (town gas) is inferior in terms of GHG emission intensity and is also characterized by a high embodied energy intensity.

The E-IO analysis used in this study has the following advantages and disadvantages compared to conventional IO analysis. The advantages are:

- Improvement in data accuracy: To employ conventional IO, it is necessary to collect reliable x_{ij} which is monetary amount of transaction. Each price that constitutes the amount of transaction already reflects the desire of market participants so it is vulnerable to market distortion. However, if IO table consisting of amount of physical units from the start, such distortion can be removed as prices are generally excluded.
- Easier to data handling: E-IO table excludes variations in space and time associated with prices and only sums up physical amount of usage so it is easier to data mining and manipulating the amount of energy use.
- Excellent use of policy application: The results of E-IO analysis appear in the form of energy and environment units so they can be easily understood for policy makers in this field.

Despite these advantages, the disadvantages of E-IO usually occur when estimating the E-IO table based on the conventional IO tables. The main disadvantages are:

- Drop in the accuracy of data: If E-IO table is formulated based on conventional IO after some time has passed, reliable energy prices, which are vulnerable to variations in time and

sector, hard to get accurately analyzed. Hence such E-IO table will be fundamentally limited in terms of accuracy.

- Possibility of dispute over the validity of applied price as a proper representation: If same price is used for energy prices when estimating the amount of material (e.g., average price or midyear price), the value obtained can be represented statistically but not economically.

Nonetheless, E-IO can be precisely mapping to conventional IO if accurate energy price is analyzed and both can be converted to each other as illustrated in Chung [36].

Notwithstanding the merits of the E-IO analysis, our estimates are different from the values reported in the official national reports. The reason for this discrepancy needs to be studied further.

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Chapter 4. A Time-series Energy Input-Output Analysis of Energy Use and Associated GHG Emissions in Korea

A time-series energy input-output analysis for building an infrastructure for the energy and environment policy in Korea, *Energy and Environment*, 2009;20(6): pp875-899

E-IO table in 2000 has been created in chapter 3. In this chapter, four sequential 96×96 hybrid units E-IO tables at five-year intervals from 1985 to 2000 are created based on the same methodology. Using these four sequential matrices, the energy intensities and the GHG emission intensities, caused by energy use, are estimated for each sector. Some recommendations are made to improve this model.

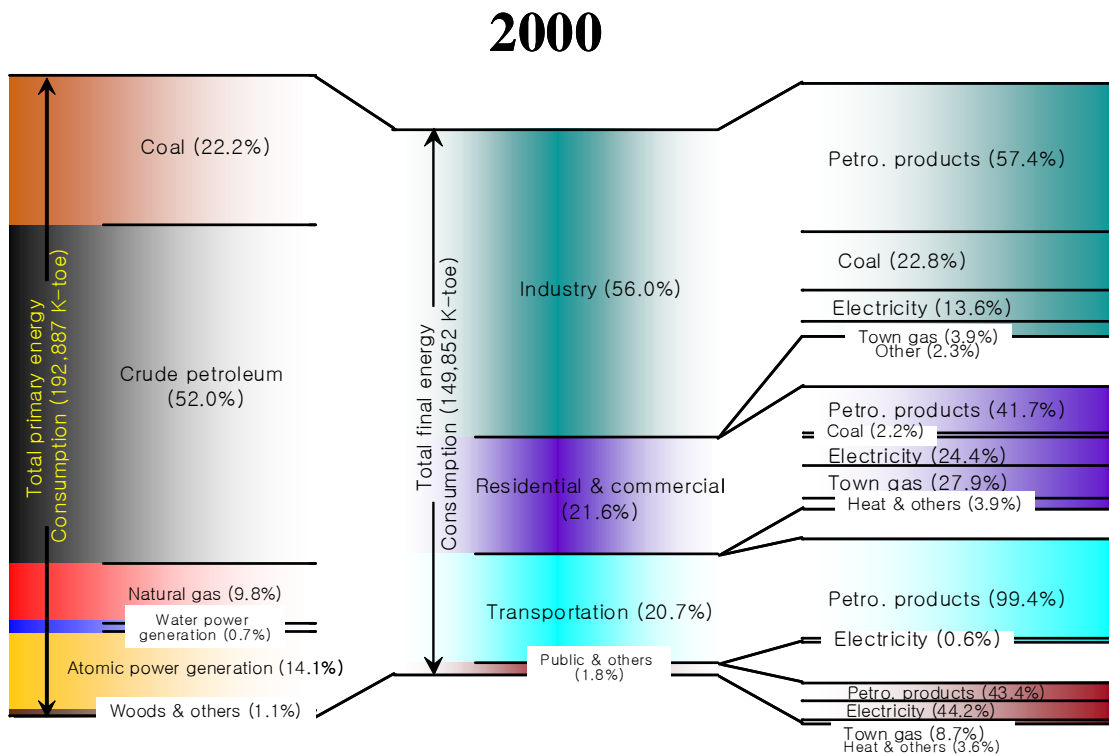
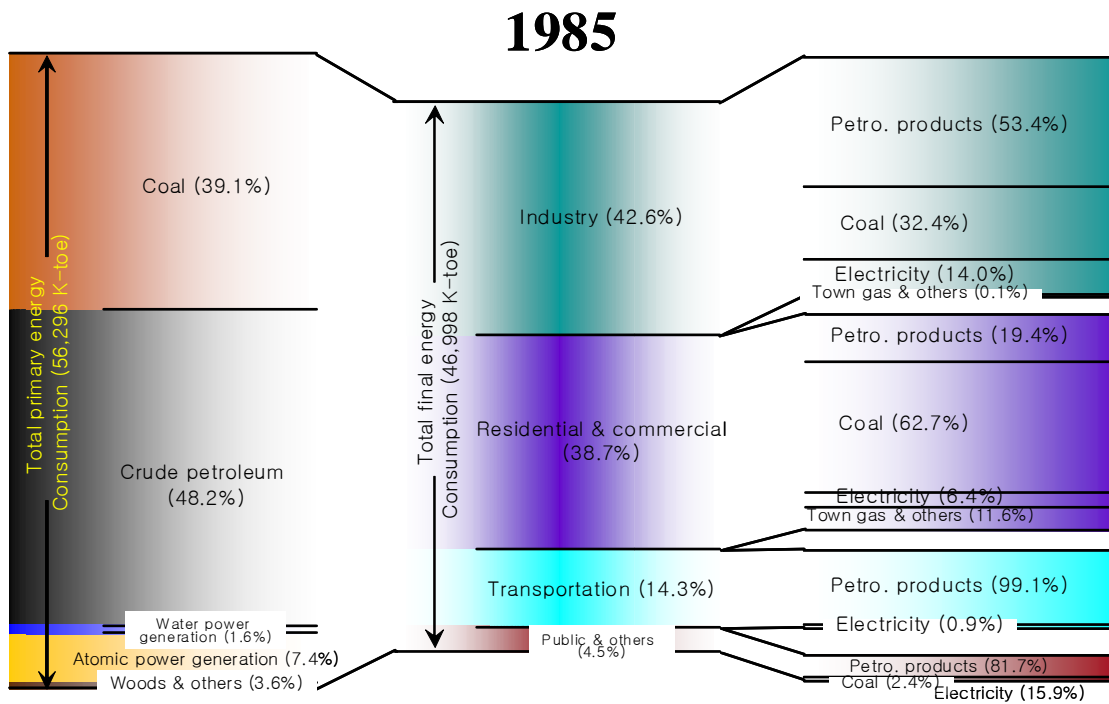
4.1 Introduction

4.1.1 Energy consumptions in Korea

Even after the Asian financial crisis in 1997–1998, which hit Korea particularly hard, Korea's primary energy consumption more than tripled during 1985–2000, i.e., from 54.7 million TOE in 1985 to 191.2 million TOE in 2000 [1]. This amounted to an average annual growth rate (AAGR) of 8.6% in primary energy consumption during that period. With regard to the energy source, the consumption of high carbon containing coal and oil changed from 40.3% to 49.6% in 1985 and from 22.4% to 52.5% in 2000 from their share of total primary energy consumption. In contrast, the shares of low carbon containing gas and renewable energies, including atomic and hydro power, increased from 0.0% to 10.1% in 1985 and from 9.9 % to 15.1% in 2000, respectively.

With regard to the energy type of the final energy consumption, petroleum products made up the largest share for each user group. Coal is the second most prevalent energy source, although its usage remained relatively static between 1985 and 2000 because the consumption of more environment-friendly town gas and carbon-free electricity increased, as shown in Figure 4.1.

According to KEEI [2], Korea's GHG emissions have increased gradually from 247.7 million tons of carbon dioxide (Mt-CO₂) in 1990 to 498.6 Mt-CO₂ in 2005, in the energy sector. Further, its share also increased from 81.1% in 1990 to 83.6% in 2005.



Source) Yearbook of energy statistics, KEEI, 1999 and 2006

Figure 4.1 Korea's energy flow in 1985 and 2000.

4.1.2 Greenhouse gas emissions in Korea

Korea's GHG emissions amounted to an AAGR of 4.8% in the energy sector during 1990–2005. Over this period, the GHG emissions from the energy industries and transport sectors increased by 10.6% and 5.8% per annum, respectively. However, the rate of GHG emissions has decreased for the energy industries (3.1%), manufacturing & construction industries (0.4%), and transport industries (1.2%) from 2000 until 2005 when compared with the entire period. (Table 4.1)

Table 4.1 GHG emissions in Korea (Mt-CO₂ eq)

	1990	1995	2000	2005	AAGR (%)	
					1990–2005	2000–2005
From energy	247.7	372.1	438.5	498.6	4.8	1.3
1) energy combustion						
a. energy industries	38.0	83.2	125.9	171.1	10.6	3.1
b. manuf. & const.	82.0	124.2	141.8	148.2	4.0	0.4
c. transport	42.4	77.2	87.1	98.2	5.8	1.2
d. others	79.9	84.3	79.3	75.2	–0.4	–0.5
subtotal	242.3	368.9	434.1	492.7	4.8	1.3
2) fugitive emissions						
a. coal	4.8	1.6	1.2	0.8	–11.3	–4.0
b. oil & natural gas	0.6	1.6	3.2	5.1	15.3	4.8
subtotal	5.4	3.2	4.4	5.9	0.6	3.0
From non-energy	26.0	58.6	51.9	59.6	5.7	1.4
National total	273.7	430.7	490.4	558.2	4.9	1.3

Remarks: The figures are amended in the latest version.

Source: http://www.gihoo.or.kr/portal/01_General_Info/04_ST01_02.jsp.

According to WRI [3], Korea ranked 1st in the world for its GHG emissions growth rate during 1990–2002. Further, for the percentile changes in non-CO₂ GHG emissions during the same period, Korea ranked 2nd in the world with a growth rate of 49%. As of 2000, only Saudi Arabia, the largest petroleum exporting country, emitted more non-CO₂ GHGs than Korea in the world.

Korea is a non-Annex I country under the Kyoto Protocol and thus is not committed to reducing its GHG emissions. Nevertheless, Korea has devoted its efforts to reduce its GHG emissions. For instance, the Presidential Commission on Sustainable Development of the Republic of Korea has issued a report, “National strategy for sustainable development of the Republic of Korea, 2006~2010,” in October 2006, in which the major goals in energy and global environmental conservation area are proclaimed as follows:

- Improve the stable energy provision
- Convert into a low energy-consumption economy
- Build an environment-friendly energy supply system

- Upgrade energy technology and an R&D system
- Build a foundation for implementing agreements
- Carry out GHG reduction project for important sector
- Establish a foundation that adapts to climate change

The various policy action items that have been executed until now were insufficient to substantially reduce the GHG emissions from Korea's energy use. The Annex I countries no longer exempt Korea from GHG emissions policy. In order to prevent an international paradigm such as a post-Kyoto Regime, Korea must launch specific action items. Currently, Korea having a 4% GHG emissions reduction target by 2020 from a 2005 baseline is eager to substitute the policies that were based on a rule of thumb as well as social distortion and search for effective and efficient policies.

For the first step to establish an efficient policy in energy conservation and mitigating GHG emissions, it is important to understand the interrelations among economic activities, energy use, and GHG emissions in Korea. Furthermore time-series analysis of economy, energy and GHG emission data is useful to determine how the trends were changed and what factors impacted.

For such purposes, a time series E-IO analysis was conducted on the basis of monetary input-output (IO) tables from 1985 to 2000 in Korea. Through E-IO analysis, the interrelations among economy, energy, and GHG emissions were analyzed. It is to be noted that the IO tables used in this study were issued by the BOK. The benchmark IO table of 2000 was the newest one in Korea at the submission stage to the journal of Energy and Environment.

4.2 Preceding study review

There are many studies in the world regarding an energy analysis and/or an environmental analysis with an IO approach. Previous studies of energy or environmental IO analysis have already been reviewed in chapter 1 and the studies are summarized in Table 1.6.

4.2.1 Composition of the E-IO table

4.2.1.1 Composition of the E-IO table with hybrid units

The E-IO tables were composed on the basis of the corresponding IO table issued by the BOK every five years. In the E-IO table, energy sectors are expressed in units of a ton of oil equivalent (TOE), while the other sectors follow the conventional IO table approach and are expressed in monetary units (Korean Won, KRW). Therefore, if viewed column-wise, the table consists of values with different units, i.e., TOE and KRW, while row-wise the values are of the same unit. Therefore, for the energy sectors, the row values show the energy distribution structure for each sector and their sum equals the total output of the corresponding energy sector. Meanwhile, for the non-energy sectors, the row values signify the distribution structure of the total output. Detailed composition was described in chapter 3.

4.2.1.2 Expansion to linked E-IO tables

To create linked E-IO tables, each year's E-IO table, which is based on the current price, must be converted so that it is based on the constant price. The target of conversion should be the monetary amount reflected in the transactions between industrial sectors and their final demand. The rows already substituted by energy units do not go through any conversion. In the case of BOK, in order to create linked IO tables, the constant price is not computed by converting the current value added for each cell, but instead the double deflation method is used for constant price with respect to the total value added. This research used the method of BOK. Double deflation is a useful method in calculation of real GDP, which deflates nominal price of intermediate transactions and output using proper price index and subtract real intermediate input from real output. The method has been applied in the system of national accounts of 1993 (SNA 93).

4.2.2 Validation of the composed E-IO table

4.2.2.1 Appropriateness of the energy data

Energy statistics in Korea are composed by the Korea Energy Economy Institute (KEEI). The E-IO table must be composed on the basis of professional statistics on energy. This study, however, composed energy quantity data on the basis of annual average price data issued by the BOK because the statistics, the classification standard of the sectors, and the aggregated items presented in the energy balance sheets included in the Energy Statistics 2000 issued by KEEI and BOK are not consistent.

This study composed quantity data of the energy sources by the following steps:

- 1) Calculate unit prices for each energy source from the supplementary table in the IO table from the BOK
- 2) In the case of many energy products in one sector (e.g., oil products include various kinds of lubricants and refined petroleum products), a weighted average was considered as a unit price
- 3) Convert various kinds of energy units (e.g., metric ton for primary coal, kilo liters for gasoline, and barrel for crude petroleum) into TOE
- 4) Calculate the total energy used from the original transaction matrix

This approach is comparatively accurate because it uses averaged national values for the energy sources when the sectoral price variation of the energy sources is small. However, when the sectoral price variation of the energy sources is large, this approach is not accurate. The sectoral price variation for an energy source except electricity was small at the corresponding year in Korea [1].

In this study, each sector was aggregated into three groups which have similar energy consumption behavior. The grouping was necessary in order to maximize utilization of results for the energy and GHG policy. Table 4.2 shows the aggregated results of the differences between the energy consumption data calculated by this study (E-IO) and the data from the

census of the national energy statistics as compared to the primary energy consumption by KEEI.

Table 4.2 Comparison of the primary energy consumption

(unit: M-TOE)

Energy source	1985			1990			1995			2000		
	E-IO	KEEI	%	E-IO	KEEI	%	E-IO	KEEI	%	E-IO	KEEI	%
<i>Coal</i>	23.0	22.0	105	23.5	24.4	96	31.9	28.1	114	43.9	42.9	102
Crude petroleum	27.7	27.1	102	42.0	50.2	84	85.5	94.0	91	121.9	100.3	122
Natural gas	0	0	-	2.9	3.0	96	8.8	9.2	95	19.8	18.9	105
Water power generation	0.3	0.9	34	0.5	1.6	34	0.5	1.4	34	0.5	1.4	35
Thermal & self-power generation	3.6	8.6	43	5.0	11.4	44	10.5	24.7	43	14.5	32.3	45
Atomic power generation	1.4	4.2	34	4.4	13.2	34	5.8	16.8	34	9.4	27.2	34

As shown in Table 4.2, the values in the E-IO and energy balance sheet of KEEI are not always acceptable. The differences are mainly from the following two reasons.

First, they have a fundamental difference for aggregating accounts. For example, the energy balance sheet of the KEEI includes transformation, stock change, and exports but excludes international bunkers. The E-IO includes these items; if these accounts are eliminated from the E-IO, the original differences could reduce as described in chapter 3.

Next, the aggregated standards are different. For example, errors are generated in the power generation technologies because the KEEI's values were surveyed on the basis of an energy input to a power station, but the E-IO's values were aggregated by electricity produced by power stations. Because of these reasons, energy consumption data, used as a power sector among the 14 energy sources in the E-IO table, are expressed as energy input to generated electricity. Therefore, thermal power reveals a 43-45% error and water and atomic energy reveal 34-35% errors, which are nearly equal to power generation efficiency.

Additionally, this study assumed the use of only wood energy and so it must separate the consumption data from renewable energies in the KEEI statistics. This study, however, did not include wood energy because of lack of reliable data for wood consumption as primary energy.

4.2.2.2 Confirmation of the necessary conditions

The E-IO tables from 1985 to 2000 used in this study were verified to satisfy the following two conditions.

- In terms of an energy balance, the total primary energy intensity of a product should be equal to the total secondary energy intensity of the product plus the amount of energy lost in energy conversion. This signifies that it should satisfy the energy conservation condition.
- In terms of linear algebra, conditions ensuring a non-negativity of the total outputs computed in the Leontief inverse matrix and producibility in economics. This signifies that it should satisfy the Hawkins-Simon (H-S) condition [28].

Among these, the energy conservation condition can usually be compensated by the laws of thermodynamics. Since the power generation sector has a thermal efficiency of 45% in the case of thermal & self-power generation and a thermal efficiency of 35% in the case of atomic power generation, their energy loss can be compensated artificially applying the energy concept in an E-IO table. However, this study did not have to compensate because the original IO table announced by BOK had been composed based on transaction amount of electricity not based on energy input.

Next, Miller and Blair [7] introduced an H-S condition to obtain a non-negative solution in a Leontief model, so that a non-negative output will result from a given non-negative final demand. This condition was checked in this study by the following steps:

- For the $(\mathbf{I}-\mathbf{A}^*)$ coefficients matrix to satisfy the H-S conditions, it can be checked by the following two steps. First, all the diagonal elements of the matrix must be positive and all the non-diagonal elements of the matrix must meet a precondition, which is non-positive. The E-IO table from 1985 to 2000 used in this study satisfies the precondition.
- Next, the results of the calculation of the determinants values for all the leading principle sub-matrices of the $(\mathbf{I}-\mathbf{A}^*)$ for each table showed that all the minors were positive, which means all the $(\mathbf{I}-\mathbf{A}^*)$ matrices composed in this study satisfy the H-S condition.
- Therefore, the Leontief inverse matrix, $(\mathbf{I}-\mathbf{A}^*)^{-1}$, was found to satisfy the H-S conditions, as well.

4.2.3 Selection of the GHGs

As described in chapter 3, we have selected three GHGs of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which cause a direct greenhouse effect in IPCC (1996). The emission coefficients for these compounds are calculated by considering the average calorific values of 14 energy sources used in Korea. GHG emissions from each sector were determined by the same procedures in chapter 3.

4.3 Methodology

4.3.1 E-IO analysis procedure

An estimation of the energy and GHG emissions intensities from energy use with an E-IO analysis has a few differences when compared to using a conventional IO analysis. Generally, the analysis begins with three components. (Figure 4.2)

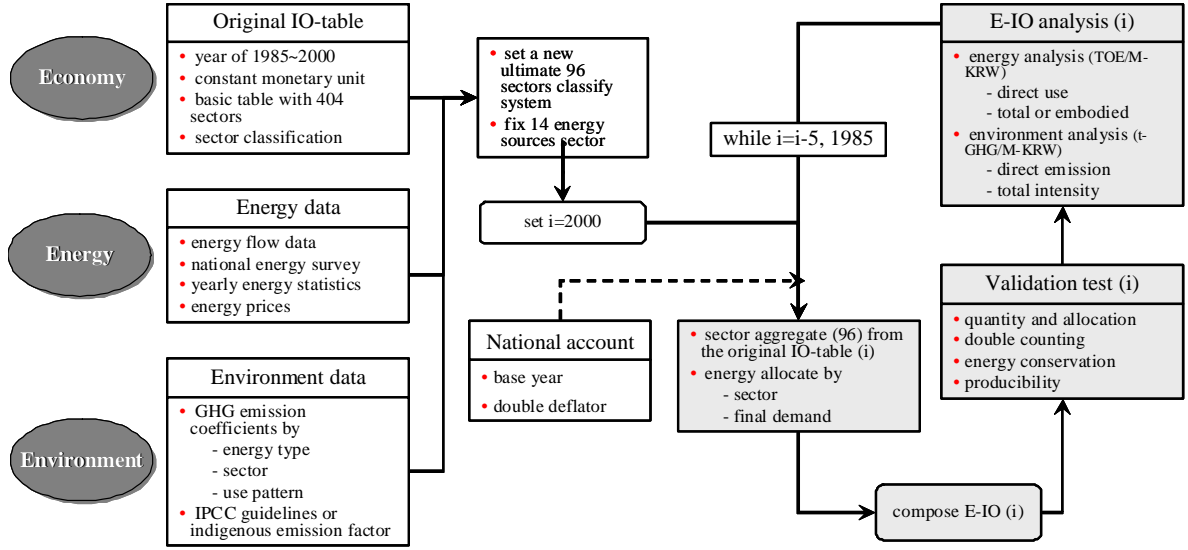


Figure 4.2 Process of time-series E-IO analysis.

The method for obtaining an energy intensity and GHG emissions intensity through an E-IO table was already presented in detail in chapter 3. Hereafter the computation procedure is summarized.

The input coefficient matrix consists of four elements of heterogeneous characteristics, as shown in Eq. (4.1).

$$A^* = Z^* (\widehat{X^*})^{-1} = \begin{bmatrix} toe/toe & toe/\$ \\ \$/toe & \$/\$ \end{bmatrix} \quad (4.1)$$

Here, Z^* is a new transaction matrix because k energy sectors in a conventional input-output table has changed row-wise from monetary price to energy unit. X^* represents a total output vector that is mixed with monetary units and energy units according to sectors as well. The hat (^) that is shown here represents that the elements of a vector is changed into a diagonal matrix. The superscript (*) on the matrix implies that the energy sectors consist of an energy unit and the non-energy sectors consist of a monetary unit.

Direct energy coefficients (\mathbf{EI}_δ) and total or embodied energy coefficients (\mathbf{EI}_α) can be found using Eqs. (4.2) and (4.3).

$$\mathbf{EI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{A}^* \quad (4.2)$$

$$\mathbf{EI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} (\mathbf{I} - \mathbf{A}^*)^{-1} \quad (4.3)$$

\mathbf{F}^* is an artificial vector that remains energy rows in a matrix. $(\mathbf{I} - \mathbf{A}^*)^{-1}$ matrix has the same characteristic as \mathbf{A}^* shown in Eq. (4.1). \mathbf{A}^* and $(\mathbf{I} - \mathbf{A}^*)^{-1}$ matrices represent an input or technical coefficients matrix and a Leontief inverse matrix, such as the conventional IO, respectively.

Here, both \mathbf{F} and \mathbf{X} are vectors and each are defined as the total energy consumption for an economy (the elements of non-energy sectors consist of 0) and the total output (non-energy sectors consist of money and energy sectors consist of amount of consumption), respectively.

Direct or total emission intensity of a GHG is denoted as \mathbf{GI} ; the \mathbf{GI} of the intermediate transaction sectors by energy use is shown in Eqs. (4.4) and (4.5); \mathbf{GI}_δ and \mathbf{GI}_α are matrices of the $k \times n$ that designate the GHG emissions intensity caused by direct energy use and total energy use, respectively.

$$\mathbf{GI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{M} \mathbf{A}^* \quad (4.4)$$

$$\mathbf{GI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{M} (\mathbf{I} - \mathbf{A}^*)^{-1} \quad (4.5)$$

Here, \mathbf{M} is an $n \times n$ dimensional symmetric matrix and it was modified to incorporate Korea's situation on the basis of IPCC (1996). The elements of the matrix represent the coefficients of the GHG (CO_2 , CH_4 , and N_2O) emissions associated with energy consumption in each industry. The unit of the elements is the emissions of each GHG under evaluation per unit energy consumption (e.g., t- CO_2 /TOE or g- CH_4 /J).

4.3.2 Modification of the GHG emission factor

For the assessment of GHG emissions caused by energy consumption, the emission factors of the IPCC Guidelines revised in 1996 were used. This study, however, partly modified the factors on the basis of IPCC [29] by considering the specific conditions in Korea as described in chapter 3. The modification was performed according to the recommendations of the IPCC [29] for two aspects. One was to consider the fraction of carbon stored and the fraction of carbon oxidized for each energy source to reflect a different use pattern for the 14 energy sources. The other was that since the energy sources were combined into 14 sectors, the emission factors were modified by a weighted average for a component rate of the included energy sources. The modification results as a result of reflecting the time series situation of each E-IO table are summarized in Table 4.3. We need to treat CO_2 emissions factor for three power generation sectors to zero to prevent double calculation in both at power generation stage and at electricity usage stage.

In 2007, IPCC [31] issued an updated guideline report on an emission coefficient in “IPCC 2006 Guidelines for National Greenhouse Gas Inventories,” which was not formally applied for national report. Key World Energy Statistics 2007 [18] still used the IPCC Guidelines 1996, which was not used internally. This provides consistent viewpoints on the previous GHG emissions statistics of Korea. According to these backgrounds, this study will use the emissions coefficients of the IPCC Guidelines 1996.

Table 4.3 Modification of the CO₂ emission factors by energy source

Name of sector	Emission factor (t-CO ₂ /TOE)				Included fuels
	1985	1990	1995	2000	
Coal	3.758	3.733	3.718	3.708	
Crude petroleum	3.009	3.009	3.009	3.009	
Natural gas	2.298	2.298	2.298	2.298	
Coal products	4.077	4.077	4.077	4.077	BKB & Patent fuel, Coke, Coal briquette, etc.
Naphtha	0.752	0.752	0.752	0.752	
Gasoline	2.842	2.842	2.842	2.842	Jet oil A-1, P-4
Fuel oil	3.057	3.026	3.011	2.974	Kerosene, Diesel, Bunker A~C, LPG
Misc. petroleum refinery products	0.775	0.775	0.775	0.775	Asphalt, Lubricant, Paraffin wax, etc.
Water power generation	0.000	0.000	0.000	0.000	
Thermal and self-power generation	0.000	0.000	0.000	0.000	
Atomic power generation	0.000	0.000	0.000	0.000	
Town gas	2.677	2.423	2.400	2.334	Naphtha, Propane, LNG
Heat	0.000	0.000	0.000	0.000	LNG, LSWR, Bunker C, Waste burning
Wood	4.178	4.178	4.178	4.178	

4.3.3 Validation of estimated GHG emissions

The amounts of GHG emissions estimated in this study were compared with those of KEEI [32]. N₂O was overestimated by 137%. CO₂ was converted from an underestimated value to an overestimated value in 2000, while CH₄ exhibited an opposite trend in 1995. (Table 4.4)

In this study, the error was considered to be acceptable and no further analyses were made due to the two grounds. At first, there is an uncertainty involved in deciding whether the E-IO table in this study or KEEI [32] that would be the most likely estimate for the value, which was estimated by most of the Annex-I parties. Secondly, even the inherent limitations of the IO analysis still remain in an E-IO analysis, such as price distortion in a unit conversion,

aggregation error in setting up a sector, and missing a necessary item in a sector. Both estimations do not put in an awkward position but in a mutually complementary role.

Table 4.4 Comparison of the estimation tendency for the GHG emissions

Year	Element	E-IO (2008)			KEEI (2003)		Comparison (a/b)
		total	direct (a)	unit	actual (b)	unit	
1985 **	CO ₂	413	158	Mt-CO ₂	229	Mt-CO ₂	69%
	CH ₄	137,643	124,588	t-CH ₄	1,895	kt-CO ₂ eq	138%
	N ₂ O	5,029	2,136	t-N ₂ O	353	kt-CO ₂ eq	188%
1990	CO ₂	533	186	Mt-CO ₂	248	Mt-CO ₂ eq	75%
	CH ₄	135,260	116,781	t-CH ₄	1,503	kt-CO ₂ eq	163%
	N ₂ O	6,204	24,05	t-N ₂ O	480	kt-CO ₂ eq	155%
1995	CO ₂	1,022	349	Mt-CO ₂	372	Mt-CO ₂	94%
	CH ₄	76,519	37,724	t-CH ₄	992	kt-CO ₂ eq	80%
	N ₂ O	11,772	4,453	t-N ₂ O	714	kt-CO ₂ eq	193%
2000	CO ₂	1,372	509	Mt-CO ₂	439	Mt-CO ₂	116%
	CH ₄	83,565	35,499	t-CH ₄	918	kt-CO ₂ eq	81%
	N ₂ O	16,201	6,832	t-N ₂ O	894	kt-CO ₂ eq	237%

Remarks: Figures in column KEEI (2003) is extrapolated for this study

4.4 Results

Since intensity denotes a total amount of input required for a unit value-added production (million Korean Won (M-KRW) in this study), it can be applied to both direct energy use and total or embodied energy use. In this study, however, to avoid any confusion, “factor” refers to direct energy use and “intensity” refers to total or embodied energy use.

Energy consumption factors and GHG emission factors of direct energy use will be shown as a whole, while energy intensities and GHG emissions intensities of total energy use will be explained in more detail compared to direct use..

4.4.1 Energy use and GHG emission factors

The analysis of energy use and GHG emissions from direct energy use was performed using Eqs. (4.2) and (4.4). The results obtained from direct energy use during 1985–2000 are summarized as follows (Table 4.5):

- When we look at the energy use factors with respect to the average annual values (0.166 (1985), 0.142 (1990), 0.135(1995), and 0.132 (2000)), gradual improvements have been shown since 1985. The GHG emissions factors were 0.429 (1985), 0.344(1990), 0.310 (1995), and 0.306 (2000) and steady improvement was seen during 1985–2000.
- Sector 10 (thermal & self-power generation) showed the highest factors of energy use and GHG emissions throughout the entire period.

Table 4.5 Sectoral energy use factor and its GHG emissions factor

Sector code	Energy use factor (TOE/M-KRW)				GHG emission factor (t-CO ₂ -eq./M-KRW)				
	1985	1990	1995	2000	1985	1990	1995	2000	
Energy group	1	0.0056	0.0034	0.0012	0.0007	0.0089	0.0031	0.0012	0.0007
	2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	4	0.0047	0.0127	0.0207	0.0105	0.0126	0.0252	0.0482	0.0216
	5	0.0172	0.0114	0.0065	0.0054	0.0487	0.0297	0.0165	0.0126
	6	0.0305	0.0227	0.0499	0.0586	0.0877	0.0593	0.1362	0.1504
	7	0.0239	0.0182	0.0235	0.0251	0.0686	0.0473	0.0646	0.0617
	8	0.3994	0.2211	0.1693	0.1430	0.6386	0.2735	0.1824	0.1602
	9	0.0135	0.2856	0.1685	0.0241	0.0351	0.0394	0.0420	0.0347
	10	2.4418	2.1166	2.2400	2.4401	8.3281	6.8555	7.2879	8.3515
	11	0.0114	0.0652	0.0737	0.0297	0.0312	0.0320	0.0313	0.0181
	12	1.1276	0.4310	0.2174	0.0360	1.9930	1.2625	0.6377	0.0905
	13	1.2285	0.7635	0.6347	0.9027	3.7477	2.3353	1.1938	2.0277
	14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Non-energy & energy intensive group	15	0.0004	0.0505	0.0668	0.0245	0.0006	0.1533	0.2008	0.0727
	16	0.1935	0.3019	0.3245	0.3154	0.5926	0.8911	0.9350	0.8896
	17	0.0290	0.0077	0.0052	0.0014	0.0482	0.0090	0.0115	0.0024
	18	0.1487	0.1946	0.1850	0.1737	0.3387	0.3750	0.4428	0.4087
	19	0.1489	0.1512	0.1115	0.1197	0.4151	0.4231	0.2935	0.2539
	20	0.0759	0.0749	0.0641	0.0734	0.1287	0.1396	0.1240	0.1211
	21	0.4059	0.3003	0.4190	0.4185	1.1337	0.8056	0.9217	0.7079
	22	0.0561	0.0450	0.0503	0.0713	0.1422	0.0975	0.1081	0.1459
	23	0.1687	0.1430	0.1197	0.1284	0.4100	0.3400	0.2474	0.2371
	24	0.8973	0.8077	1.1500	1.1368	1.1484	0.8023	1.0570	1.0284
	25	0.5380	0.3507	0.2560	0.2839	1.5955	1.0137	0.6250	0.5333
	26	0.1520	0.0449	0.0818	0.1113	0.0966	0.0069	0.1088	0.1137
	27	0.2703	0.1982	0.1280	0.1128	0.5551	0.3511	0.2083	0.1391
	28	0.6546	0.5510	0.4649	0.2996	0.8282	0.6481	0.5430	0.3948
	29	0.0751	0.0861	0.0671	0.0727	0.1565	0.1718	0.1232	0.1283
	30	0.3830	0.4019	0.2411	0.2125	1.0732	1.0712	0.6129	0.4947
	31	0.4379	0.3971	0.3723	0.3342	1.3220	1.1396	1.0585	0.9167
	32	1.0640	0.6887	0.4891	0.4963	3.6693	2.3072	1.5287	1.5219
	33	0.5917	0.6835	0.6814	0.6488	1.3178	1.1320	1.0817	1.0388
	34	0.7027	0.5989	0.6379	0.6511	2.6371	2.1717	2.3825	2.4390
	35	0.0978	0.0854	0.0754	0.0810	0.2411	0.1936	0.1398	0.1125
	36	0.1928	0.1163	0.0800	0.0586	0.5755	0.3259	0.1840	0.0833
	37	0.0737	0.0539	0.0845	0.0892	0.1547	0.0851	0.1547	0.1621
	38	0.0459	0.0304	0.0562	0.0808	0.0948	0.0364	0.0597	0.0823
	39	0.0989	0.1010	0.0993	0.0652	0.2799	0.2652	0.2511	0.1291
	40	0.1235	0.1180	0.0823	0.0866	0.3383	0.3281	0.1968	0.2048
	41	0.3953	0.4881	0.5471	0.5244	1.1646	1.3721	1.5601	1.4817
	42	0.0977	0.0868	0.0741	0.0596	0.2649	0.2272	0.1715	0.1269
	43	0.1645	0.1357	0.1423	0.1454	0.0262	0.0266	0.0530	0.0599
	44	0.1270	0.2376	0.1898	0.1790	0.2682	0.5540	0.4715	0.4150
	45	0.0468	0.0764	0.1670	0.1467	0.1106	0.1624	0.2519	0.1960
Non-energy & energy less-intensive group	46	0.0099	0.0156	0.0202	0.0265	0.0374	0.0464	0.0603	0.0779
	47	0.0501	0.0494	0.0662	0.0644	0.1711	0.1237	0.1776	0.1657
	48	0.0011	0.0108	0.0076	0.0168	0.0032	0.0229	0.0166	0.0358
	49	0.0231	0.0236	0.0246	0.0207	0.0583	0.0549	0.0571	0.0460
	50	0.0548	0.0338	0.0305	0.0288	0.1242	0.0785	0.0726	0.0692
	51	0.0059	0.0086	0.0098	0.0116	0.0089	0.0130	0.0161	0.0153
	52	0.0676	0.0608	0.0555	0.0620	0.1822	0.1537	0.1359	0.1513
	53	0.1146	0.0848	0.0602	0.0665	0.2973	0.2125	0.1473	0.1696
	54	0.0724	0.0740	0.0686	0.0621	0.2005	0.2032	0.1729	0.1579
	55	0.0654	0.0463	0.0413	0.0357	0.1764	0.1217	0.1021	0.0849
	56	0.0097	0.0157	0.0247	0.0291	0.0167	0.0351	0.0465	0.0550
	57	0.0056	0.0070	0.0068	0.0070	0.0131	0.0182	0.0145	0.0151
	58	0.0602	0.0713	0.0652	0.0573	0.1170	0.1459	0.1544	0.1241
	59	0.0400	0.0446	0.0316	0.0289	0.0851	0.0950	0.0801	0.0761
	60	0.0407	0.0467	0.0505	0.0443	0.0914	0.1038	0.1143	0.0831
	61	0.0238	0.0254	0.0253	0.0279	0.0562	0.0582	0.0607	0.0677
	62	0.0578	0.0668	0.0510	0.0495	0.1552	0.1578	0.1282	0.1195
	63	0.0598	0.0543	0.0379	0.0478	0.1539	0.1327	0.0847	0.0984
	64	0.0174	0.0168	0.0243	0.0294	0.0378	0.0380	0.0524	0.0585
	65	0.1089	0.1315	0.0658	0.0655	0.1367	0.1435	0.1204	0.0963
	66	0.0294	0.0250	0.0409	0.0418	0.0689	0.0608	0.0943	0.0959

67	0.0392	0.0320	0.0338	0.0331	0.0920	0.0701	0.0765	0.0647
68	0.0711	0.0592	0.0805	0.0722	0.1374	0.1121	0.1809	0.1413
69	0.1078	0.0780	0.0765	0.0920	0.2382	0.1633	0.1533	0.1722
70	0.0852	0.1007	0.0809	0.0533	0.1946	0.1766	0.1449	0.0876
71	0.0577	0.0313	0.0298	0.0320	0.1298	0.0567	0.0638	0.0659
72	0.0230	0.0265	0.0218	0.0281	0.0532	0.0515	0.0401	0.0536
73	0.0282	0.0157	0.0205	0.0293	0.0666	0.0268	0.0358	0.0458
74	0.0345	0.0478	0.0314	0.0349	0.0682	0.0735	0.0557	0.0546
75	0.0359	0.0298	0.0247	0.0143	0.0589	0.0379	0.0334	0.0179
76	0.0167	0.0202	0.0119	0.0109	0.0297	0.0297	0.0213	0.0160
77	0.0221	0.0145	0.0055	0.0039	0.0396	0.0154	0.0098	0.0066
78	0.0337	0.0257	0.0203	0.0187	0.0766	0.0534	0.0387	0.0358
79	0.0138	0.0087	0.0101	0.0114	0.0277	0.0130	0.0159	0.0190
80	0.0419	0.0386	0.0320	0.0356	0.0994	0.0686	0.0487	0.0512
81	0.0224	0.0171	0.0151	0.0194	0.0424	0.0389	0.0285	0.0354
82	0.0184	0.0161	0.0170	0.0221	0.0437	0.0257	0.0311	0.0360
83	0.0393	0.0462	0.0376	0.0406	0.0832	0.1090	0.0905	0.0946
84	0.0406	0.0345	0.0358	0.0404	0.0959	0.0821	0.0769	0.0768
85	0.0126	0.0144	0.0140	0.0188	0.0292	0.0304	0.0353	0.0431
86	0.0682	0.0699	0.0377	0.0433	0.1427	0.1446	0.1017	0.1021
87	0.0410	0.0832	0.0410	0.0354	0.1036	0.2225	0.1111	0.0895
88	0.0632	0.0422	0.0301	0.0212	0.1114	0.0636	0.0429	0.0281
89	0.0268	0.0276	0.0186	0.0151	0.0500	0.0569	0.0367	0.0266
90	0.0294	0.0262	0.0340	0.0263	0.0464	0.0303	0.0319	0.0183
91	0.0426	0.0390	0.0392	0.0272	0.1043	0.0933	0.1026	0.0666
92	0.0282	0.0334	0.0407	0.0535	0.0841	0.0920	0.0979	0.1175
93	0.0628	0.0461	0.0432	0.0343	0.1658	0.1141	0.1003	0.0665
94	0.1001	0.0752	0.0632	0.0523	0.2158	0.1472	0.1260	0.1003
95	0.0778	0.0685	0.0390	0.0607	0.1892	0.1893	0.0981	0.1172
96	0.0158	0.0159	0.0208	0.0244	0.0582	0.0561	0.0686	0.0559

- Among the 96 sectors, sector 12 (town gas) showed the largest improvement in terms of the energy use factor and the GHG emissions factor; on the other hand, sector 15 (Crops-p) showed the largest deterioration for both factors. The improvement in sector 12 was because the input fuel was changed from petroleum gas in 1985 to natural gas in 2000, and the deterioration in sector 15 was due to the spread of agricultural facilities and a rapid growth in the demand of electricity for the facilities.

4.4.2 Energy and GHG emission intensities from total energy use

Total energy use is an IO concept that incorporates direct energy use and indirect energy use. The evaluation of energy use and GHG emissions was performed using Eqs. (4.3) and (4.5). Time series characteristics are explained by dividing 96 sectors into 3 predetermined groups.

In Figures 4.3 through 4.6, the blue column means that the energy or GHG emission intensity was improved in the final year 2000 as compared to the start year 1985. Red bar means that the index was even or worse in 2000 than 1985. And the line segment attached to the column shows outlier between 1985 and 2000.

4.4.2.1 Embodied energy intensity

The estimated values showed the following characteristics. The unit is TOE/M-KRW (Figure 4.3).

- Energy group (sector-1 through -14, see (a) in Figure 4.3)

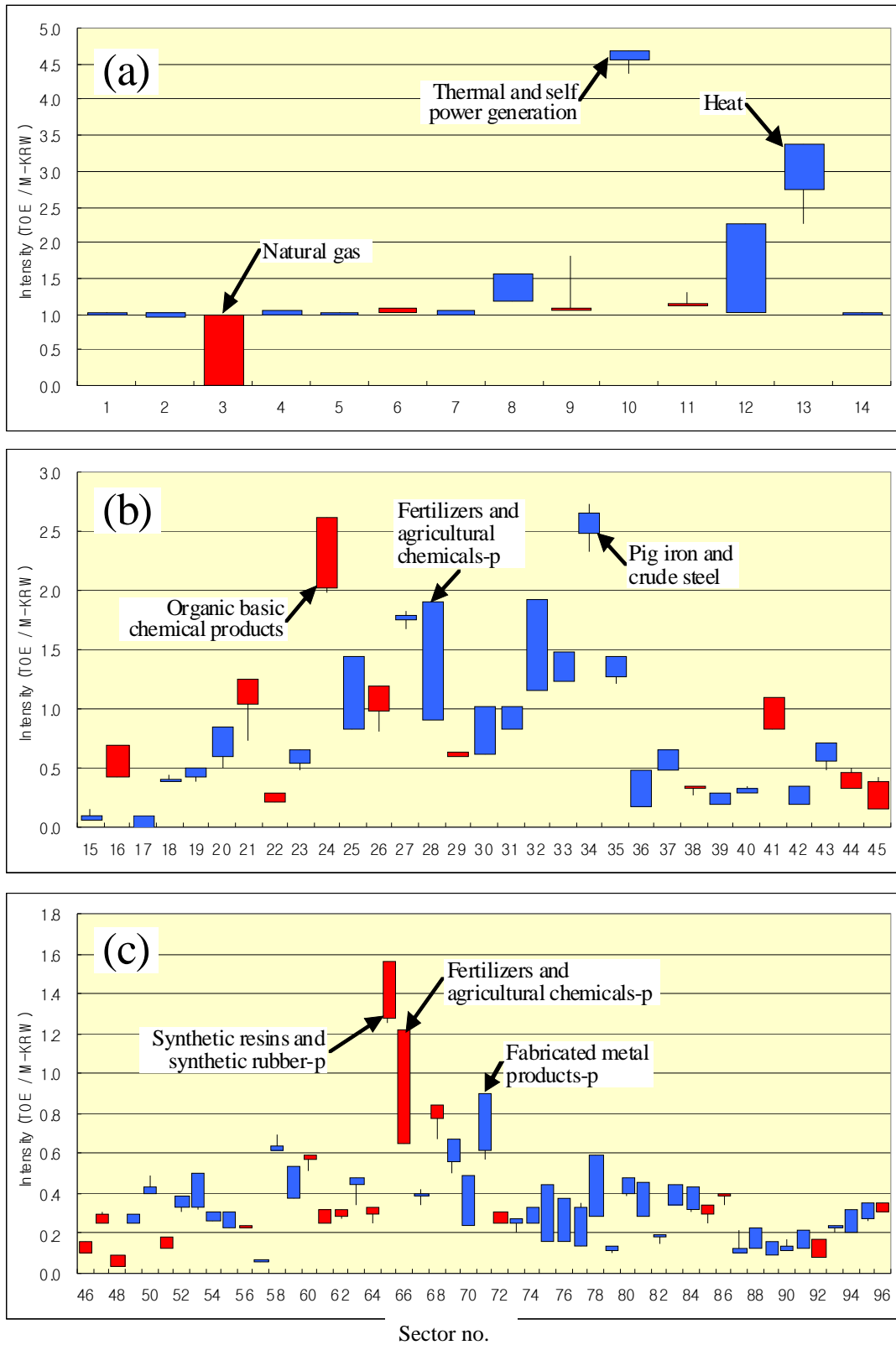


Figure 4.3 Embodied energy intensity for three separate groups.

Most sectors showed improvement between 1985 and 2000 and the annual averages of these 14 sectors were 1.514 (1985), 1.466 (1990), 1.442 (1995), and 1.426 (2000); the values decreased gradually. The most notable feature was deterioration in sector 3 (natural gas) that was introduced in 1986 and an improvement in sector 12 (town gas).

- Energy intensive group in the non-energy group (sector-15 through -45, see (b) in Figure 4.3)

There were more sectors showing improvement than those showing deterioration and the annual averages of these 31 sectors were 0.876 (1985), 0.768 (1990), 0.798 (1995), and 0.784 (2000); the values decreased gradually. The notable sector was sector 28 (Fertilizers and agricultural chemicals-p), which showed an improvement of more than double.

- Energy less-intensive group in the non-energy group (sector-46 through -96, see (c) in Figure 4.3)

There were more sectors showing improvement than those showing deterioration and the annual averages of the 51 sectors were 0.372 (1985), 0.338 (1990), 0.333 (1995), and 0.336 (2000); the values decreased gradually. The notable sector was sector 66 (fertilizers and agricultural chemicals-p), which showed a considerable deterioration of more than double. This is contrary to the improvement for this sector mentioned in the previous paragraph. This implies that the fertilizers and agricultural chemicals sectors are divided into two extremes in terms of their efficiency.

4.4.2.2 Embodied GHG emission intensity

1) CO₂ emission intensity

The decreasing trend in the CO₂ emission intensity was shown for the 96 sectors (Figure 4.4). The annual averages were 1.844 (1985), 1.578 (1990), 1.548 (1995), and 1.525 (2000); the values appeared to be decreasing gradually. Sector 10 (thermal and self-power generation) and sector 34 (pig iron and crude steel) showed rapid improvements, while sector 3 (natural gas) denoted red column since it was used from 1986 in Korea.

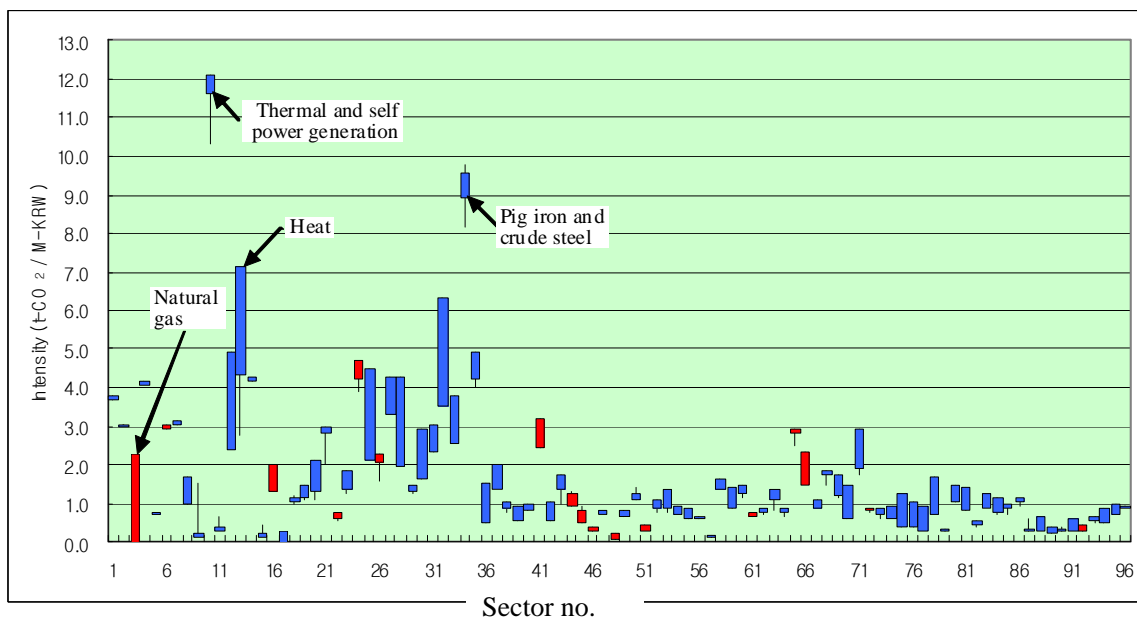


Figure 4.4 Change of the CO₂ emission intensities during 1985-2000.

2) CH₄ emission intensity

The CH₄ emission intensity showed decreasing trend for the 96 sectors (Figure 4.5). The annual averages were 0.150 (1985), 0.120 (1990), 0.134 (1995), and 0.123 (2000); the values decreased gradually. Sector 13 (heat) and sector 47 (livestock breeding) showed rapid improvements, while sector 41 (transportation and warehousing-p) got worse.

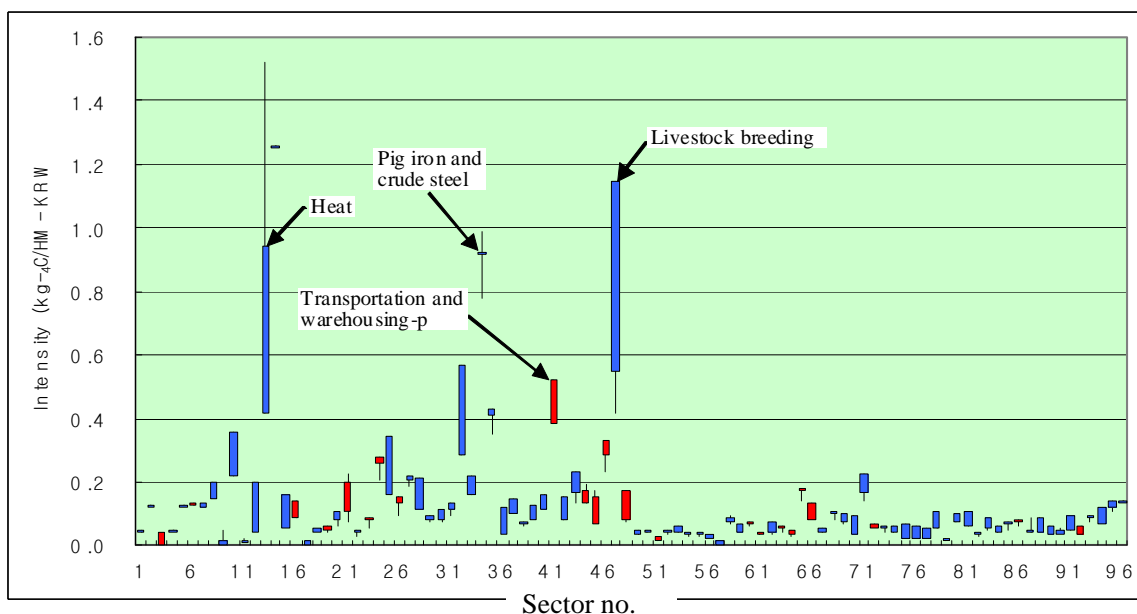


Figure 4.5 Change of the CH₄ emission intensities during 1985-2000.

3) N₂O emission intensity

The N₂O emission intensity decreased for the 96 sectors (Figure 4.6). The annual averages were 0.024 (1985), 0.020 (1990), 0.022 (1995), and 0.020 (2000); the values remained about the same. However, two sectors showed rapid improvements—sector 13 (heat) and sector 34 (pig iron and crude steel). On the other hand, sector 10 (thermal and self-power generation) went through deterioration along with large emissions.

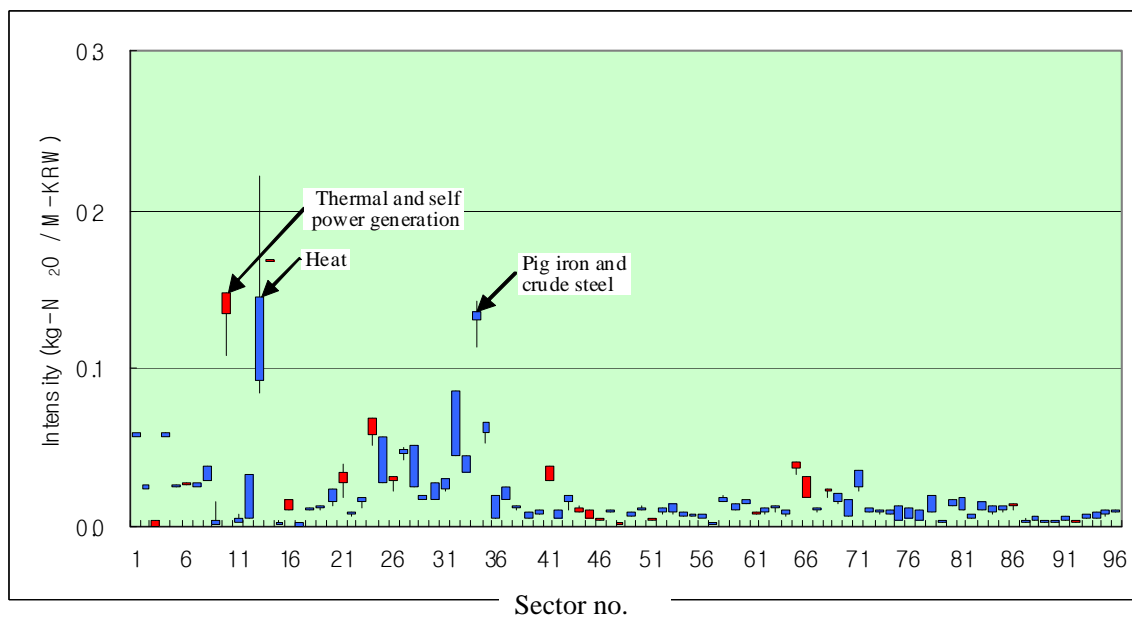


Figure 4.6 Change of the N₂O emission intensities during 1985-2000.

4.4.2.3 Scattering patterns and linear fittings

The distribution patterns of the time-series energy and GHG emission intensities for each group are shown in Figure 4.7. The scattered numbers for each graph represent the numbers for the 96 sectors and the slanting red solid line represents the result of the linear fitting that passes through the point of origin, which enables us to examine the relationship between the embodied energy consumption intensity (TOE/M-KRW, shown at the X-axis) and the embodied GHG emissions intensity (g-CO₂-eq./M-KRW, shown at the Y-axis).

The changes in the slope of this line signify the rate of change in GHG emissions intensity with respect to a change in the energy intensity. Therefore, if the value of the slope decreases with time, it means that the corresponding group's GHG emissions intensity has been improved. In contrast, an increasing value of the slope implies that the GHG emission intensity has been degraded. Both the energy intensive group and the energy less-intensive group, including the non-energy sector, showed a gradual improvement during 1985–2000. On the other hand, the energy group went through a lot of improvements between 1985 and 1990, but its GHG emissions intensity increased between 1990 and 2000. This shows that the GHG emissions from the energy sectors, especially in sector 10(thermal and self-power generation), contributed to increase of Korea's GHG emissions significantly. (Figure 4.8) It varied depending on the

ratio of coal usage in sector 10 of transformation sector. The share of thermal power generation rose gradually in the 57.5% in 2005 from 45.0% in 1990 in Korea.

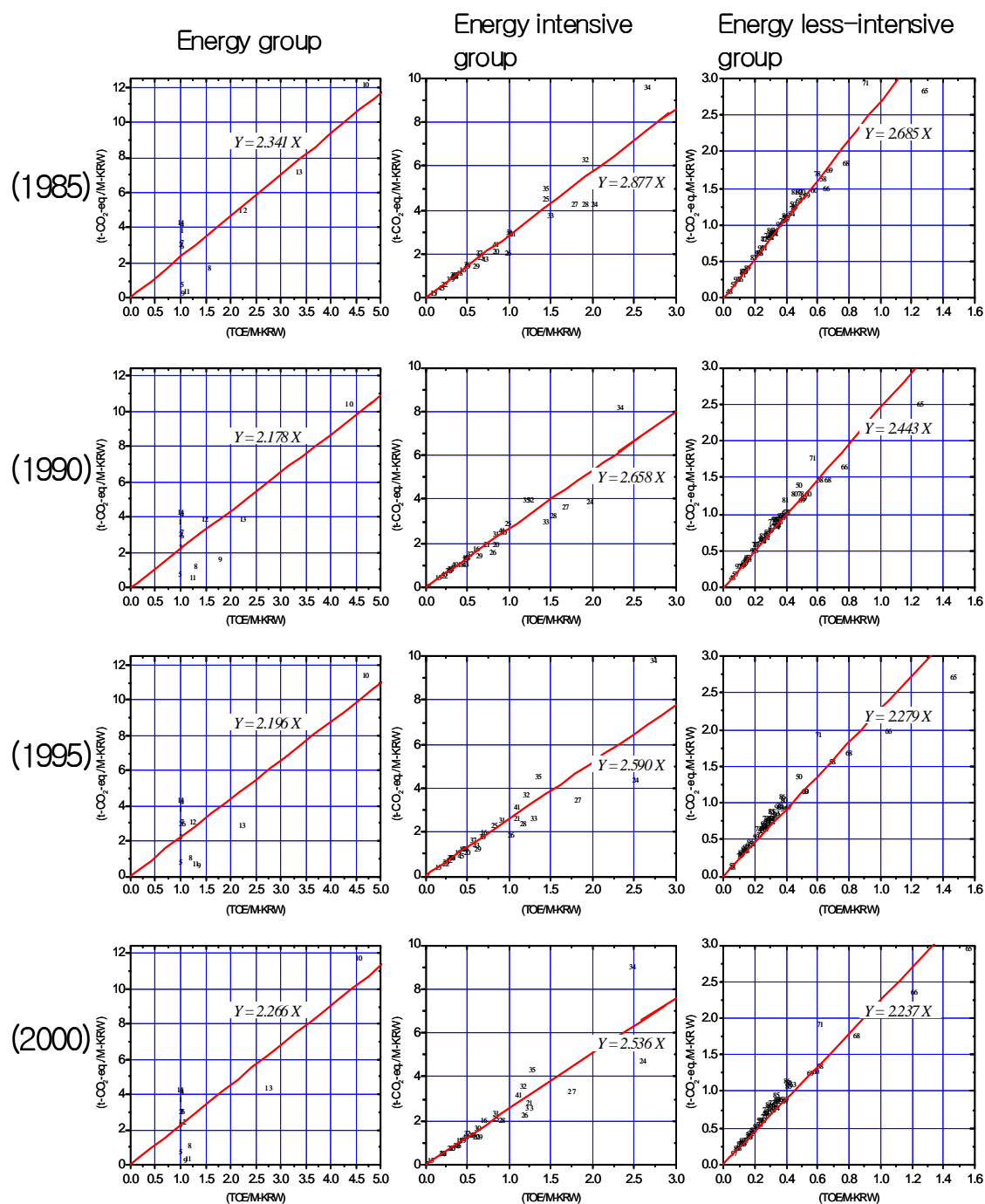


Figure 4.7 Temporal distribution changes in total intensities in each group.

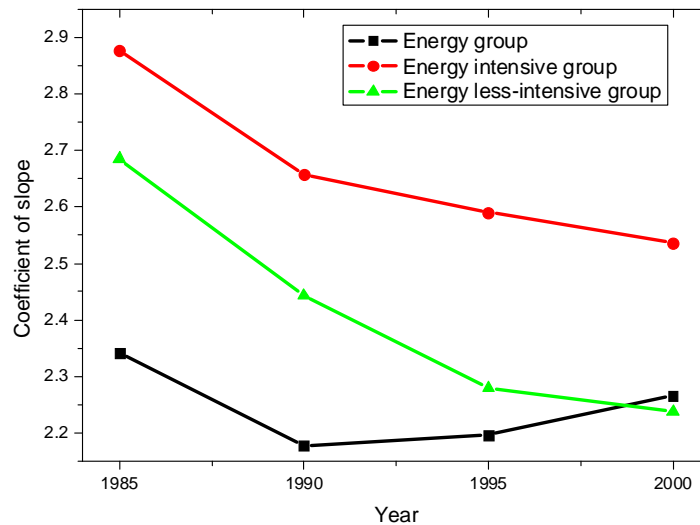


Figure 4.8 Changes in coefficients of slope for each group.

4.5 Summary and policy recommendations

E-IO analysis was performed on the basis of 96 aggregated sectors, including 14 energy sources, and their total (embodied) energy and GHG emission intensities were calculated. The results imply that if the major goal is to save expense for energy imports, then sectors with high energy consumption intensity have to be regulated; if the goal is to meet Korea's declaration to the GHG emission abatement, then sectors with high GHG emission intensity would have to be regulated; and if both these goals are important simultaneously, then sectors located far from the point of origin would have to be regulated as shown in Figure 4.7.

A metric model to describe a climate change must include not only direct emissions of a pollution source but also induced indirect emissions. An assessment that incorporates indirect emissions is a task that should be considered carefully during the discussions for a new regime such as a post-Kyoto Protocol that encourages the participation of developing countries. This is because it is difficult to expect an actual worldwide or nationwide decrease in pollutant emissions if countries or industries simply transfer emissions from one to another. Moreover, not only does a national climate change countermeasure decrease a pollutant's emissions, but it also directly affects the sustainable growth of an economy. Since the enforcing of environmental policies has a profound effect upon an economic progress, a metric analysis of the relationship among economy, energy, and environment is essential.

The results of this analysis can be applied to the measurement of load sharing in terms of energy and GHG emissions between entities in intra-industry assessment, and direction of structural changes in inter-industry policy as well,

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Chapter 5. Index Decomposition Analysis of Changes in Energy-related Sectoral GHG Emissions in Korea

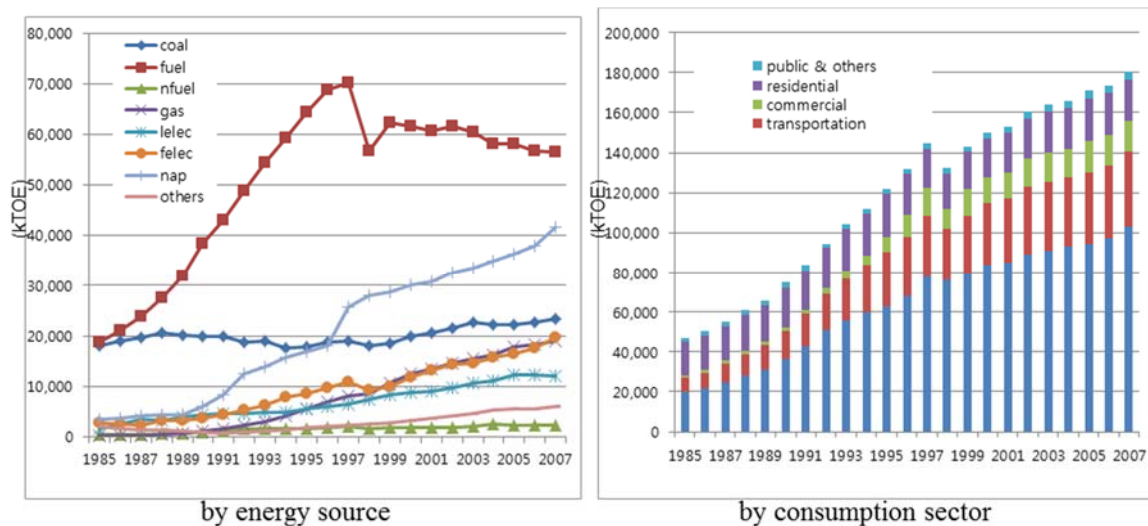
Socio-Technological Impact Analysis using an Energy IO Approach to GHG Emissions Issues in Korea, *Applied Energy*, 2011; 88: pp.3747-3758.

Through E-IO analyses from 1985 to 2005, the changes in three factors affecting GHG emissions in Korea are analyzed. Based on the E-IO results, the changes in the direct and total (embodied) GHG emissions from the pertinent sectors are decomposed into three factors—the energy consumption effect, the social effect, and the technological effect—using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005.

5.1 Introduction

5.1.1 State of Korea's energy and environment

According to the energy statistics of Korea [1], Korea accomplished rapid industrial growth after the 1980s. It was this period when the nation's energy consumption and greenhouse gas (GHG) emissions from the industrial sector increased dramatically. According to the official government statistics, the annual final energy consumption increased from 46,998 kTOE in 1985 to 180,543 kTOE in 2007, representing an annual average rate of 7.0%, as shown in Figure 5.1. Energy was grouped into the following eight categories: Coal, Fuel, non-fuel oil (Nfuel), Gas, low-carbon electricity generation (Lelec), fossil fuel electricity generation (Felec), naphtha (Nap) and district heating (Heat).



Remarks: “Coal” includes coal and coal products; “Fuel” includes gasoline, fuel oil, and LPG; “Nfuel” includes non-fuel oil—crude oil, lubricants, and others; “Gas” comprises natural gas and city gas. “Lelec” represents low-carbon electricity generation, which includes hydro power generation and atomic power generation. “Felec” denotes fossil fuel electricity generation, which includes thermal power generation. “Nap” stands for naphtha. “Heat” includes thermal energy for district heating.

Source: KEEI, Yearbook of Energy Statistics

Figure 5.1 Trend in final energy consumption in Korea.

In the final energy consumption structure of Korea, the relative importance of the consumption of Coal and Fuel were reduced from their 1985 levels of 38.2% and 39.9%, respectively, to 13.0% and 31.3% in 2007. On the other hand, the relative importance of the consumption of Nfuel, Gas, Lelec, and Felec during the same period increased to 24.4%, 10.4%, 6.6%, and 10.9% in 2007 from 8.1%, 0.2%, 3.3%, and 6.0%, respectively, in 1985. The growth rate of the final energy consumption was higher than that of the GDP through the period between 1985 and 2005, as shown in Table 5.1[2]. During this period, the energy use environment of Korea was marked by the rapid spread of automobiles and distinctive changes in industrial structures. The change in the industrial structures, that is, the increase in the relative importance of the service industry as well as the increases related to automobiles and semiconductors, petrochemicals, steel, and high-value-added consumption materials led to an increasing demand for clean energy sources such as electricity and gas. The increased demand for clean energy sources also resulted in a decrease in the relative importance of lower-value-added and labor-intensive manufacturing industries such as textiles, shoes, and container manufacturing.

Table 5.1 Status of Korean economy, energy use, and GHG emissions

Item	GDP (in 2000 price)		Final energy consumption		GHG emissions in energy use		Share of intermediate sectors in energy use
Unit	Billion-KRW	AAGR(%)	kTOE	AAGR(%)	Mt-CO ₂	AAGR(%)	Share(%)
1985	202,408.0	-	46,998.0	-	na	-	86.3
1990	320,696.4	9.6	75,107.0	9.8	239.0	-	88.6
1995	467,099.2	8.7	121,962.0	10.0	366.9	9.0	85.3
2000	578,664.5	7.3	149,852.0	8.0	432.2	6.1	81.7
2005	723,126.8	6.6	170,854.0	6.7	490.5	4.9	84.8

Remarks: KRW represents monetary unit of Korean Won and AAGR denotes average annual growth rate.

GHG emissions associated with energy use stood at 490.5 Mt-CO₂ in 2005, showing an increase of 4.9% in AAGR (Average Annual Growth Rate), which was lower than that of the final energy consumption between 1990 and 2005. Among the countries in the Organization for Economic Cooperation and Development (OECD), Korea was rated as the sixth-highest country in terms of total GHG emissions in 2004. Between 1990 and 2005, the country's carbon dioxide (CO₂) emissions doubled, increasing by 105.2 %. This growth rate is the highest among OECD members according to the data from the Ministry of the Environment [3].

Although Korea does not have any binding targets under the Kyoto Protocol, the country nevertheless declared a voluntary mitigation target in November, 2009. However, for countries such as Korea, which belong to the non-Annex 1 group, it is more important to have the capability to analyze the emission characteristics of each industrial sector rather than to engage in declarations pertaining to a reduction in total emissions, so that they may be in a better position to prevent a decline in economic competitiveness in the post-Kyoto era.

The intermediate demand sector comprises approximately 85% of the final energy consumption of Korea. The energy used by the intermediate demand sector plays a very important role in the cyclical structure of the national economy because it creates added value as a direct input. Moreover, in the discussions on application of a sectoral approach to reduce GHG emissions, each country must have the capability to analyze the characteristics of the GHG emissions from its various industrial sectors. Therefore, it is important to reveal the characteristics of the energy use and environmental emissions associated with the activities of the intermediate demand sector and to analyze the socio-technological impact on these factors associated with Korean policies to reduce GHG emissions.

5.1.2 Decomposition methods

The concept of decomposition analysis was originally a basic tool in positive economics because a majority of economic data is prepared based on the concept of an economic differential and/or an index. Structural decomposition analysis (SDA) and index decomposition analysis (IDA) are typically used as preferred methods of decomposition analysis. In general, SDA uses information from IO tables, while IDA uses aggregate data at the sector level [4]. Moreover, among all decomposition analysis methods, IDA is suitable for examining and measuring production, social, technological effects using national-level data; thus, it is widely used in energy and environmental analysis, especially in the energy sector as shown in Table 5.2. Hence, IDA is considered as a type of energy decomposition analysis [4].

5.1.3 Literature review of the decomposition analysis of energy and the environment

Arithmetic mean Divisia index (AMDI) and log mean Divisia index (LMDI) methods are applicable in terms of weight function. However Ang [6] pointed out that AMDI method has two shortcomings. One of the shortcomings of the AMDI method is that it fails when the data set contains zero values, e.g. when an energy source begins or ceases to be used in a sector in the study period. The LMDI can be shown to converge when the zero values in the data set are replaced by a small positive number but the AMDI does not have this convergence property. In any of the above-mentioned situations, the LMDI method is the preferred index decomposition method from both the theoretical and application viewpoints. The results given by multiplicative decomposition and additive decomposition are related by a simple formula and interchangeable.

The most common application areas of the LMDI analysis are energy demand and supply as well as energy-related GHG emissions (Table 5.2).

Most existing studies concentrate on the decomposition of national CO₂ emissions and emission intensities of the industrial and power sectors.

Examples of decomposition studies on national CO₂ emissions (or emission intensities) include Wang et al. (2005) and Ma and Stern(2008) of China, Lin et al. (2006) of Taiwan, Hatzigeorgiou (2007) of Greece, O' Mahony et al. (2008) of Ireland, Löfgren and Muller (2008) of Sweden, Sands and Schumacher (2009) of Germany, Bacon and Bhattacharya (2007) on behalf of 70 countries, Bataille et al. (2007) representing the G7 countries, Zhang (2008)

representing 18 countries in the Middle East and North Africa, and Böhm (2009) representing 13 countries and 2 regions. Most of the studies decomposed the national CO₂ emissions growth into economic growth, fuel switching, and changes in emission intensity [7-17].

Table 5.2 Recent decomposition cases with the LMDI method

Researcher	Year of publish	Country/ Region	LMDI		Time span	Applied on
			I/II	Calc.		
Bhattacharyya & Ussanarassamee	2005	Thai	I	multi	1981-2000	energy intensity
Wang et al.	2005	China	I	add	1957-2000	CO ₂ emissions
Lin et al.	2006	Taiwan	I	add	1991-2001	CO ₂ emissions
Ang & Liu	2007	USA	I / II	add	1985-2000	energy consumption
Bacon & Bhattacharya	2007	worldwide 71 countries	I	add	1994-2004	CO ₂ emissions
Bataille et al.	2007	G7 countries	I	add	1990-2002	GHG emissions
Hatzigeorgiou et al.	2007	Greece	I	add	1990-2002	CO ₂ emissions
He et al.	2007	Liaoning province in China	I	add	1995-2005	energy intensity
Liu et al.	2007	China	I	add	1998-2005	CO ₂ emissions
Löfgren & Muller	2008	Sweden	I	add	1993-2004	carbon emissions
Ma & Stern	2008	China	I	add	1994-2003	energy intensity
O'Mahony et al.	2008	Ireland	I	add	1990-2006	CO ₂ emissions
Sandu & Syed	2008	Australia	I	add	1989-2006	energy consumption
Zhang	2008	18 countries in Middle East & North Africa Region	I	add	1995-2005	CO ₂ emissions
Zhao & Ouyang	2008	China	I	add	1998-2006	SO ₂ emission intensity
Böhm	2009	13 countries, 2 regions	I	add	1971-2005	CO ₂ emissions
Cahill & Gallachóir	2009	Irish	I	multi	1995-2007	energy consumption
Malla	2009	Australian, Canada, China, India, Japan, Korea, USA	I	add	1990-2005	CO ₂ emissions
Sands & Schumacher	2009	Germany	I	add	1995-2006	GHG emissions
Timilsina & Shrestha	2009	25 Latin American & Caribbean countries	I	multi	1980-2005	CO ₂ emissions

At the sectoral level, more studies are focused on the industrial sector than any other sectors. Liu et al. [18] decomposed CO₂ emissions growth in 36 industrial sectors in China over the period of 1998-2005. Changes in the industrial CO₂ emission are decomposed into carbon emissions coefficients of heat and electricity, energy intensity, industrial structural shift, industrial activity and final fuel shift. Zhao and Ouyang [19] analyzed SO₂ emissions from industry in China between 1998 and 2006 to identify the structure, GHG intensity, and the effect of government control. Sandu and Syed [20] examined energy consumption in industry in Australia during 1989-2006 to analyze the decomposition effect on economic activity, on structural, and on inter-fuel substitution. Cahill and Gallachóir [21] decomposed energy consumption in the Irish industry over the period 1995-2007 to examine the fuel mix and the energy intensity effect.

Some studies have concentrated on a particular industry instead of the industry sector as a whole for their decomposition analyses: Malla [22], on the electricity generation industry in seven Asia-Pacific and North American countries (Australian, Canada, China, India, Japan, Korea, USA); Ang and Liu [23], on the manufacturing and transportation sectors in the USA using both the LMDI-I and LMDI-II; and Timilsina and Shrestha [24], on the transportation industry in the Latin American and Caribbean countries.

5.1.4 Decomposition features

In the present work, IDA is used to analyze time-series changes of GHG emissions from individual sectors. IDA is considered to be suitable for analyzing time-series changes because it does not leave decomposition residual [5, 6]. This might be a rare case in analyzing GHG emissions effects from time series IO tables with IDA. Only the Lin et al. [9] and Sands and Schumacher [13] are unique studies in terms of recursive form as listed in Table 5.2.

To reveal the characteristics of the energy use and GHG emissions of the intermediate demand sector and determine the socio-technological impact on the changes of GHG emissions in Korea, a Divisia decomposition analysis was conducted using original data procured through a hybrid E-IO table. The results of the analysis were interpreted by dividing the time frame into Phase I (1985-1995), Phase II (1995-2000) and Phase III (2000-2005) based on the times when Korea began considering the climate change factor in its energy policy.

We attempt to represent the direct and total GHG emissions from each industry sector using the E-IO table. This approach must be useful in building essential data for each sector to cope with a Post-Kyoto protocol. While an analyst tries to measure the indirect demand effects of energy use, only decompositions with IO tables are possible because the Divisia decomposition analysis uses aggregate data.

The analysis conducted in this study is summarized as follows:

- Disaggregation of intermediate sectors: Economic activities in Korea were divided into 90 industries and products spanning 8 energy sources. According to change of the BOK's aggregation principle in energy sector e.g., woods, and to focus on the decomposition analysis of final energy sources, sectors was classified in this number. Classification rule for the rest of 82 sectors in non-energy group was maintained as previous chapters.
- Decomposition analysis method: The Divisia index decomposition analysis method, which is known to provide useful results with a simple operation (and is thus preferred among various decomposition analysis methods), was applied. Specifically, the LMDI-II multiplicative method, which can guarantee very accurate results in terms of linear homogeneity, was adopted [25].
- Base year of the analysis: Fixed base year makes it difficult to avoid accumulating effects as regards the appearances and extinctions of energy types in the course of serial decomposition activities, then our study used a rolling base year to eliminate this effect.
- Objects of decomposition analysis: As our analysis was carried out based on an E-IO table, it can also be applied to a direct input matrix and to a Leontief's matrix. This implies that the direct GHG emissions from the former matrix (hereinafter referred to the direct emission matrix) and the embodied GHG emissions from the latter matrix (hereinafter referred to the total emission matrix) can be estimated easily.
- Description of the analysis result: The objective function is the change in GHG emissions from energy consumption.

5.2 Model for the index decomposition method and data pertaining to energy and GHG emissions in Korea

5.2.1 Model description

We use the decomposition index (LMDI-II) in a multiplicative form (due to its linear weighted homogeneity) to analyze the changes in the GHG emissions of Korean industries. The method discussed below closely follows that in an earlier study [25].

We define the following variables:

i = energy type, $i = 1, 2, 3, \dots, 8$, referring to Coal, Fuel, Nfuel, Gas, Lelec, Felec, Nap, and Heat, respectively.

j = industrial sector, $j = 1, 2, 3, \dots, 90$

t = observation year, $t = 1985, 1990, 1995, 2000, 2005$

GHG_i = GHG (CO₂, CH₄ and N₂O) emission by energy type i (Mt-CO₂-eq.)

$GHG_{i,j}$ = GHG emission in sector j for energy type i (Mt-CO₂-eq.)

The variables below are determined for each energy type, but the suffix i is dropped.

E = total industrial energy consumption (TOE)

E_j = energy consumption in sector j (TOE)

S_j = structure of energy consumption in sector j ($= E_j / E$)

G_j = GHG emission intensity in sector j ($= GHG_j / E_j$, Mt-CO₂-eq. /TOE)

The aggregate GHG emission due to the use of energy type i from the predetermined 90 industrial sectors j can be expressed as follows:

$$GHG_i = \sum_j GHG_{i,j} \quad (5.1)$$

Eq. (5.1) can be rewritten as

$$GHG_i = \sum_j E \cdot \frac{E_j}{E} \cdot \frac{GHG_{i,j}}{E_j} \quad (5.2)$$

Eq. (5.2) is equivalent to

$$GHG_i = \sum_j E \cdot S_j \cdot G_{i,j} \quad (5.3)$$

The ratio of the aggregate GHG emission of year t to that of year $t-1$ is termed the aggregate energy intensity index. It is written as follows:

$$D_{GHG,i} = \frac{GHG_i^t}{GHG_i^{t-1}} \quad (5.4)$$

Decomposition is carried out based on this index.

Assuming that all the variables in Eq. (5.3) are continuous in time t and applying the theorem of an instantaneous growth rate to Eq. (5.3) leads to

$$d \frac{\ln(GHG_i^t)}{dt} = \sum_j \omega_j^t \left[d \frac{\ln(E^t)}{dt} + d \frac{\ln(S_j^t)}{dt} + d \frac{\ln(G_j^t)}{dt} \right] \quad (5.5)$$

Where $\omega_j^t = GHG_j^t / \sum_j GHG_j^t$ is the sector's share of GHG emissions; it is known as the weight of the sector in the summation. Integrating over time from $t-1$ to t and rearranging the terms, we get:

$$\ln \left(\frac{GHG_i^t}{GHG_i^{t-1}} \right) = \int_{t-1}^t \sum_j \omega_j^t \left[d \frac{\ln(E^t)}{dt} dt \right] + \int_{t-1}^t \sum_j \omega_j^t \left[d \frac{\ln(S_j^t)}{dt} dt \right] + \int_{t-1}^t \sum_j \omega_j^t \left[d \frac{\ln(G_j^t)}{dt} dt \right] \quad (5.6)$$

Taking the exponents of both sides of Eq. (5.6), Eq. (5.4) can be expressed in the multiplicative form as

$$D_{GHG} = D_{tot} \cdot D_{soc} \cdot D_{tech} \quad (5.7)$$

where

$$D_{tot} = \frac{E^t}{E^{t-1}} = \frac{\sum_j E_j^t}{\sum_j E_j^{t-1}} \quad (5.8)$$

$$D_{soc} = \exp \left[\sum_j \omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}} \right] = \prod_j \exp \left(\omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}} \right) = \prod_j D_{soc,j} \quad (5.9)$$

$$D_{tech} = \exp \left[\sum_j \omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}} \right] = \prod_j \exp \left(\omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}} \right) = \prod_j D_{tech,j} \quad (5.10)$$

Eq. (5.8) is obtained with a simple ratio of E_j without a complex operation; the structural factor of Eq. (5.9) denotes the energy use structure in Korean industries, implying a social effect. The emission coefficient factor of Eq. (5.10) shows the GHG emission intensity, which depends on the specific technologies relevant to energy use in sector j , implying a technological effect.

To fulfill the basic property of the weight functions, the applied weight $\omega_j^{*,t}$, as suggested by Ang and Choi[25] in Eqs. (5.8)-(5.10), is as follows:

$$\omega_j^{*,t} = \frac{L(\omega_j^t, \omega_j^{t-1})}{\sum_{k,v} L(\omega_{k,v}^t, \omega_{k,v}^{t-1})} \quad (5.11)$$

where $\omega_j^t = \frac{G_j^t}{G^t}$, $\omega_j^{t-1} = \frac{G_j^{t-1}}{G^{t-1}}$

$$L(\alpha, \beta) = \frac{\alpha - \beta}{\ln(\alpha) - \ln(\beta)}$$

Summation in the denominator on the right side of Eq. (5.11) is taken over all final energy types and sectors. Here, the residual is equal to unity.

5.2.2 Korea's energy and GHG emission data: hybrid IO tables from 1985 to 2005

Since decomposition using an established model requires the structure of sectoral energy use and an environment inventory, the energy data and GHG emission data associated with economic activities were estimated using the E-IO table in monetary unit (KRW) and energy unit (TOE). The basic concept of the energy hybrid IO analysis was introduced in an earlier study [26] and was improved later [27]. The details of Korea E-IO table are described in chapter 3. However the industry sectors were rearranged into a total of 90 sectors from 403

sector IO tables issued by the BOK, as shown in Table 5.3. The industry sectors were classified into three groups consisting of energy group, energy intensive group, and energy less-intensive group, and these contained 8 energy sectors, 31 energy intensive non-energy sectors, and 51 energy less-intensive non-energy sectors, respectively. The final two groups are rearranged according to the Euclidean distance from the origin of rectangular coordinates based on the final energy input ratio at each industry and final energy input to the economy input as a whole [30]. The suffix “-p” at the end of some sectors’ names in non-energy group shows, although they have the same name, original sectors listed in the original 169×169 sector IO table are rearranged into two different group according to the distance.

Table 5.3 Sector classification of intermediate industries in Korea

Group	Code and sector name
Energy group	1-Coal, 2-Fuel, 3-Nfuel, 4-Gas, 5-Lelec, 6-Felec, 7-Nap, 8- Heat
energy intensive group	9-Crops-p, 10-Fishery products, 11-Metallic minerals, 12-Nonmetallic minerals, 13-Sugar and starches 14-Fiber yarn, 15-Fiber fabrics-p, 16-Wood and it's products-p, 17-Pulp and paper-p, 18-Organic basic chemical products, 19-Inorganic basic chemical products, 20-Synthetic resins, synthetic rubber-p, 21-Chemical fibers, 22-Fertilizers, agricultural chemicals-p, 23-Other chemical products, 24-Glass products, 25-Pottery and clay products, 26-Cement and concrete products, 27-Other nonmetallic mineral products, 28-Pig iron and crude steel, 29-Primary iron and steel products, 30-Nonferrous metal ingots and primary nonferrous metal products-p, 31-Fabricated metal products-p, 32-Machinery and equipment of general purpose-p, 33-Wholesale and retail trade, 34-Eating and drinking places, and hotels and other lodging places, 35-Transportation and warehousing-p, 36-Public administration and defense, 37-Gas and water supply, 38-Medical and health services, and social security-p, 39-Other services-p
Non-energy group	40-Crops-p, 41-Livestock breeding, 42-Forestry products, 43-Meat and dairy products, 44-Processed seafood products, 45-Polished grains, flour and milled cereals, 46-Bakery and confectionery products, noodles, 47-Seasonings and fats and oils, 48-Canned or cured fruits and vegetables and misc. food preparations, 49-Beverages, 50-Prepared livestock feeds, 51-Tobacco products, 52-Fiber yarn-p, 53-Wearing apparels and apparel accessories, 54-Other fabricated textile products, 55-Leather and fur products, 56-Wood and wooden products-p, 57-Pulp and paper-p, 58-Printing, publishing and reproduction of recorded media, 59-Synthetic resins and synthetic rubber-p, 60-Fertilizers and agricultural chemicals-p, 61-Drugs, cosmetics, and soap, 62-Plastic products, 63-Rubber products, 64-Nonferrous metal ingots and primary nonferrous metal products-p, 65-Fabricated metal products-p, 66-Machinery and equipment of general purpose-p, 67-Machinery and equipment of special purpose, 68-Electronic machinery, equipment and supplies, 69-Electronic components and accessories, 70-Radio, television and communications equipment, 71-Computer and office equipment, 72-Household electrical appliances, 73-Precision instruments, 74-Motor vehicles, 75-Ship building and repairing, 76-Other transportation equipment, 77-Furniture, 78-Other manufacturing products, 79-Building construction and repair, 80-Civil Engineering, 81-Transportation and warehousing-p, 82-Communications and broadcasting, 83-Finance and insurance, 84-Real estate agencies and rental, 85-Business services, 86-Educational and research services, 87-Medical and health services, and social security, 88-Culture and recreational services, 89-Other services, 90-Nonclassifiable activities
energy less-intensive group	

In the E-IO tables, matrix \mathbf{A}^* can be easily calculated, as follows:

$$\mathbf{A}^* = \mathbf{Z}^* \cdot (\hat{\mathbf{X}}^*)^{-1} = \begin{bmatrix} \frac{TOE}{TOE} & \frac{TOE}{KRW} \\ \frac{KRW}{TOE} & \frac{KRW}{KRW} \end{bmatrix} \quad (5.12)$$

Here, \mathbf{Z}^* is a matrix with a dimension of 90×90. It is also a new transaction matrix because the eight energy sectors in a conventional IO table have to undergo a change in their rows, from

representing a monetary price to representing an energy unit. Thus, this matrix is comprised of an original inter-sector transaction matrix \mathbf{Z} in the non-energy sectors and an energy flow matrix \mathbf{E} in the energy sectors. In addition, \mathbf{X}^* is a 90×1 vector which designates the total output; it is mixed as well with the monetary energy units according to various sectors. The caret symbol (^) represents the fact that the vector has been transformed into a diagonal matrix.

The GHGs for this study include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) as in chapters 3 and 4. The emission coefficients of these components are calculated by considering the average calorific values of the 14 energy types used in Korea. We adopted GWP (Global Warming Potential) values of 21 and 310 for CH₄ and N₂O, respectively, to calculate the CO₂-eq. emissions with respect to a 100-year time horizon, as per the recommendations of the UNFCCC.

5.2.3 Changes in energy intensities

The direct and total (embodied) energy intensities are calculated with Eqs. (5.13) and (5.14), respectively as described in chapter 3.

$$\mathbf{EI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{A}^* \quad (5.13)$$

$$\mathbf{EI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} (\mathbf{I} - \mathbf{A}^*)^{-1} \quad (5.14)$$

$\hat{\mathbf{F}}$ is a 90×90 diagonal matrix. It consists of the total energy consumption of the energy sectors with 0 for all non-energy sectors as the diagonal elements. Figures 5.2 and 5.3 show the difference of energy intensity between 1985 and 2005 ($EI_{2005} - EI_{1985}$) in Korea.

A negative value indicates that the energy intensity in 2005 was improved over that in 1985. A positive value, in contrast, indicates a measure of deterioration. Numbers written in the X-axis of Figure 5.2 - 5.5 show the industries listed in Table 5.3.

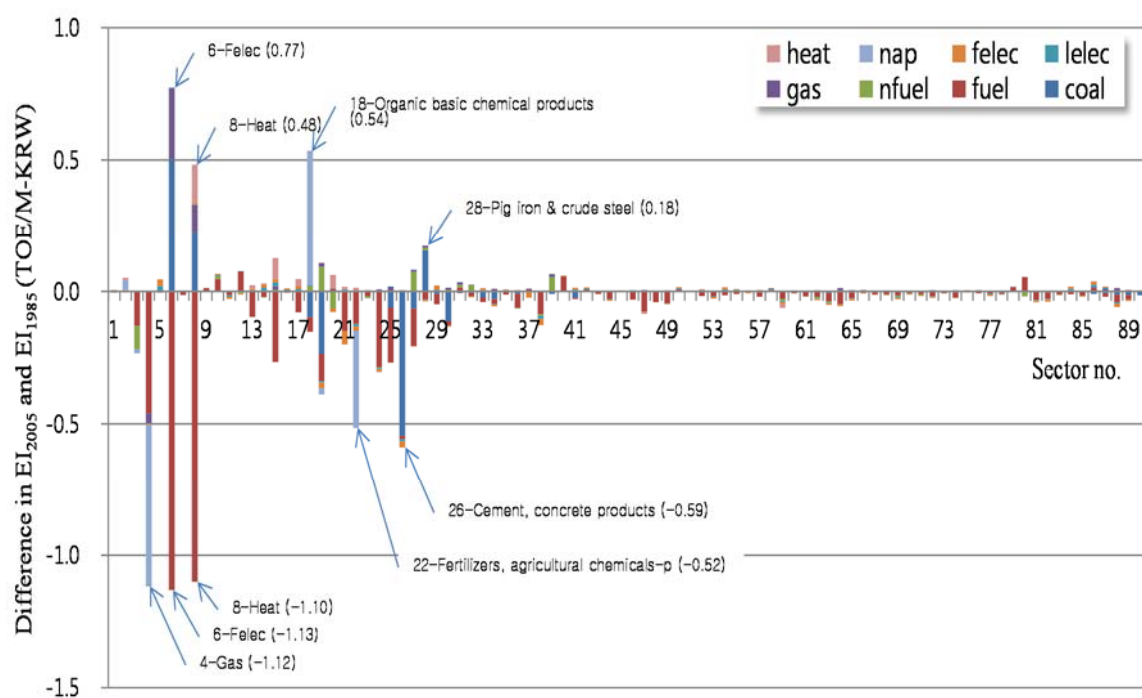


Figure 5.2 Changes in direct energy intensities between 1985 and 2005.

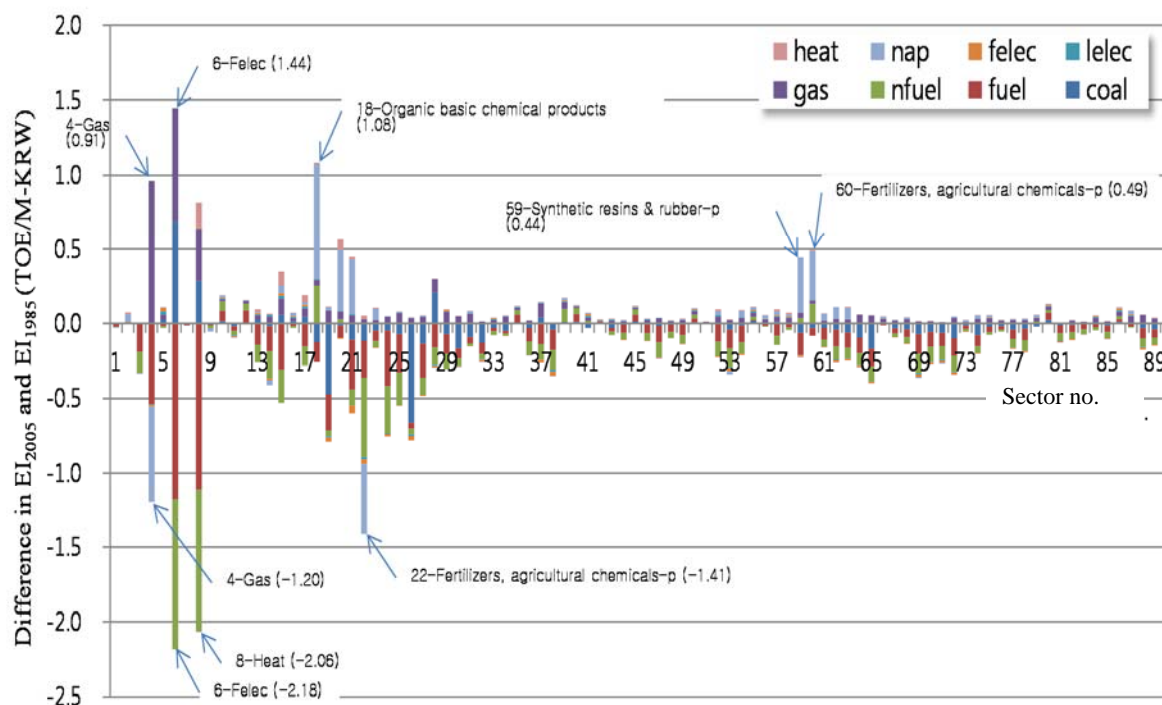


Figure 5.3 Changes in embodied energy intensities between 1985 and 2005.

The changes in the direct energy intensity can be summarized as follows (unit is TOE/M-KRW):

- Based on the changes in the intensity of the total sectors for each energy type, fuel energy-as indicated with the red bar-contributed to the largest decrease, with a total of -5.09. In contrast, gas energy contributed to the largest increase, with a total of 0.56.
- Regarding the individual sectors, a major decrease was observed in sectors #-4 (Gas, -1.12), #-6 (Felec, -1.13), #-8 (Heat, -1.10), #-22 (Fertilizers, agricultural chemicals-p, -0.52) and #-26 (Cement, concrete products, -0.59). In contrast, sectors #-6 (Felec, 0.77), #-8 (Heat, 0.48), #-18 (Organic basic chemical products, 0.54), and #-28 (Pig iron & crude steel, 0.18) demonstrated relatively significant increases.

Changes in the total (direct and induced) energy intensity, as shown in Figure 5.3, have the following characteristics (unit is TOE/M-KRW):

- Based on the changes in the intensity of the total sectors for each energy type, fuel energy showed the largest decrease of -9.10. Gas energy, on the other hand, showed the largest increase in its value, showing an increase of 4.69.
- In terms of individual sectors, sectors #-4 (Gas, -1.20), #-6 (Felec, -2.18), #-8 (Heat, -2.06), and #-22 (Fertilizers, agricultural chemicals-p, -1.41) showed a significant decrease. In contrast, sectors #-4 (Gas, 0.91), #-6 (Felec, 1.44), #-18 (Organic basic chemical products, 1.08), #-59 (Synthetic resins, synthetic rubber-p, 0.44), and #-60 (Fertilizers, agricultural chemicals-p, 0.49) showed a large increase in their values.

5.2.4 Changes in sectoral GHG emission intensities

Figures 5.4 and 5.5 indicate the range of GHG emission intensities, **GI**, from 1985 to 2005 by using Eqs. (5.15) and (5.16) as shown in chapter 3.

$$\mathbf{GI}_\delta = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1} \mathbf{M} \mathbf{A}^* \quad (5.15)$$

$$\mathbf{GI}_\alpha = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1} \mathbf{M}(\mathbf{I} - \mathbf{A}^*)^{-1} \quad (5.16)$$

M is a 90×90 dimensional symmetric matrix; it was modified to incorporate Korea's situation based on IPCC [31]. The factor M was modified according to the recommendations of the IPCC considering two points. The first considers the fraction of carbon stored and the fraction of carbon oxidized of each fuel to reflect the difference in the usage patterns of the eight energy sources. The second point considered that because the energy sources were combined into eight sectors, the emission factors were modified by the weighted average of the proportion of the included energy sources. The elements of the matrix represent coefficients of GHG emissions that occur when each industry uses fuel. Regarding the IPCC (1996) recommendation, the GHG emissions for CO₂, CH₄, and N₂O were calculated. These, however, were simplified to CO₂-equivalent emissions using the respective GWP values [31]. The unit of the matrix elements is the GHG emission of each gas under evaluation per unit use of energy (e.g., t-CO₂-eq/TOE).

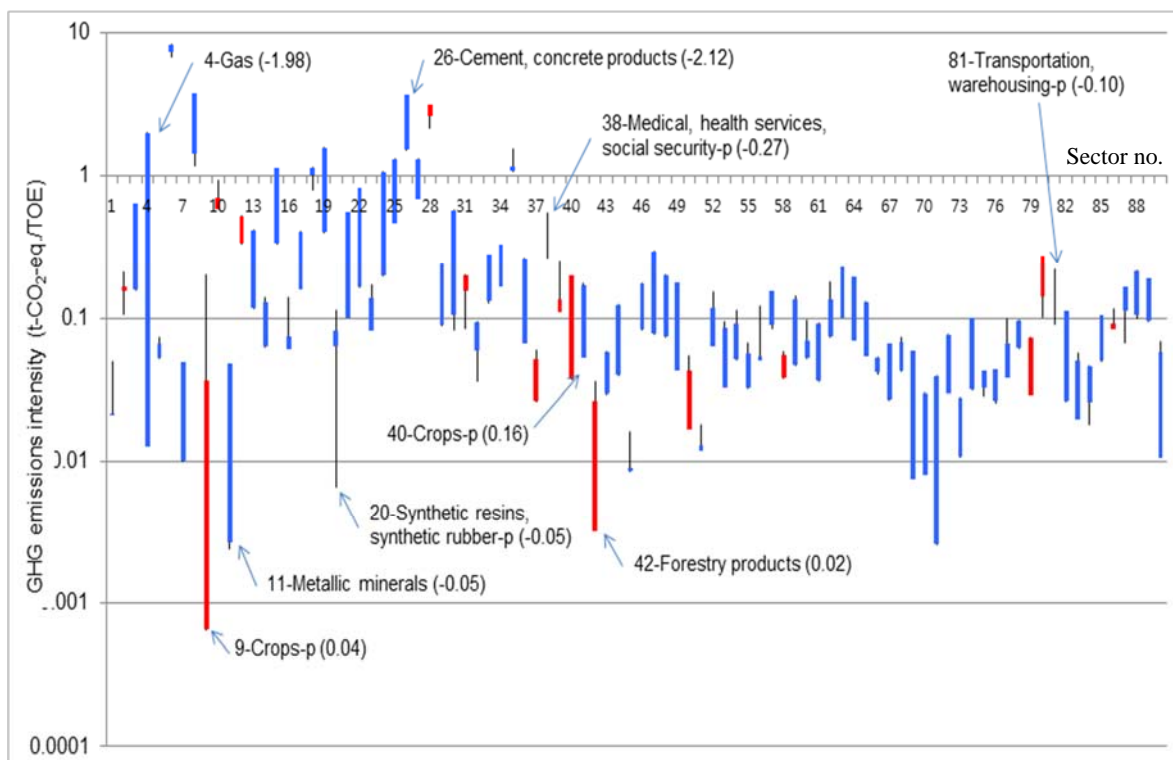


Figure 5.4 Changes in direct GHG emission intensities during 1985-2005.

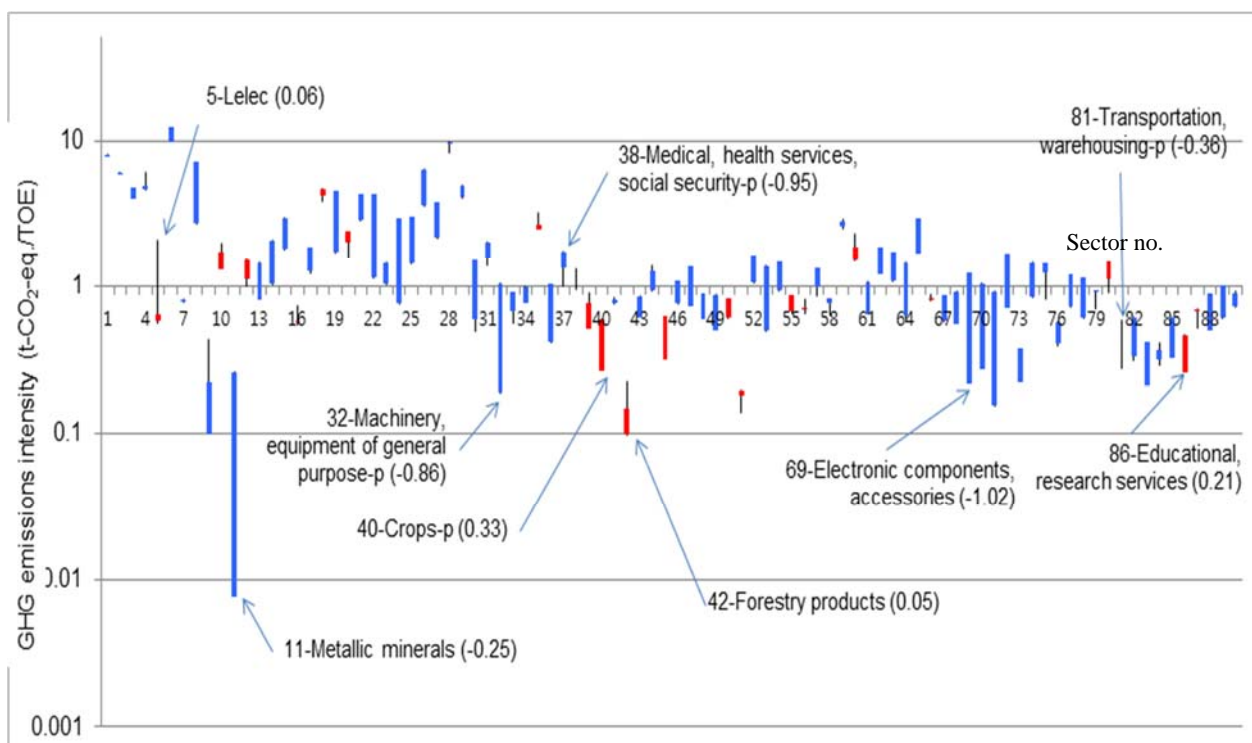


Figure 5.5 Changes in embodied GHG emission intensities during 1985-2005.

In Figures 5.4 and 5.5, the X-axis indicates 90 industrial sectors and the Y-axis denotes the GHG emissions per energy consumption (t-CO₂-eq./TOE) on a logarithmic scale. These figures are stock charts composed of blue and red bars; the blue bars indicate that the GHG emission intensity of a particular sector in 2005 decreased in comparison with that of 1985; the thick red bars imply the opposite case. In addition, the protruding black thin-line segment from the thick red or blue bars indicates a case in which the maximum or the minimum value of the changes during the corresponding period exceeds the horizon between the first year (1985) and the last year (2005).

In the direct emission matrix, a decrease in GHG emission was prominent in sectors #4 (Gas), #11 (Metallic minerals) and #26 (Cement, concrete products). In contrast, it was found that GHG emissions increased in sectors #9 (Crops-p), #40 (Crops-p), and #42 (Forestry products). In addition, although not shown prominently in the figures, sectors #20 (Synthetic resins, synthetic rubber-p), #38 (Medical, health services, social security-p), and #81 (Transportation, warehousing-p) showed frequent increases and decreases during the period of analysis (Figure 5.4).

In the total emission matrix, a decrease in GHG emission was prominent in sectors #11 (Metallic minerals), #32 (Machinery, equipment of general purpose-p) and #69 (Electronic components, accessories). In contrast, GHG emissions increased in sectors #40 (Crops-p), #42 (Forestry products), and #86 (Educational, research services)(Figure 5.5).

5.3 Results and discussions

Dietzenbacher and Stage [32] pointed out that hybrid approach may induce arbitrary results that depend on the choice of units, rather than on changes in economic structure because of an economically meaningless sum of monetary and energy units during the calculations. However, in IDA which we adopted in this study, there is no place where this unit problem could happen. This is because energy and monetary values are not summed up together for the calculation.

5.3.1 Profile of the explanation of decomposition results

Korea, which is not obliged to reduce its GHG emissions, recognized the necessity of the establishment of climate change policy since about 1990s when the UNFCCC was founded at the Earth Summit in 1992 with the subsequent adoption of the Kyoto Protocol pertaining to industrialized countries in 1997. In this study, the decomposition analysis was performed for three periods: Phase I (1985-1990, 1990-1995), Phase II (1995-2000), and Phase III (2000-2005).

5.3.2 Decomposition results of the changes in GHG emissions

In Eqs. (5.9)-(5.10), D_{soc} and D_{tech} must have positive value. However, logarithmic index is easier to identify its change than the original exponential index as shown in eq. (5.9) or (5.10). Both indices are acceptable in the sense that there is a one-to-one correspondence between them. This study used the results from logarithmic index. Thus, the decomposition analysis for sector j has been transformed as Eqs. (5.11) and (5.12).

$$D'_{soc,j} = \omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}} = \ln D_{soc,j} \quad (5.11)$$

$$D'_{tech,j} = \omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}} = \ln D_{tech,j} \quad (5.12)$$

The rest of index was also converted to logarithmic one.

$$D'_{tot,j} = \ln D_{tot,j} \quad (5.13)$$

The decomposition results with respect to the three effects are depicted in Figures 5.6 and 5.7 using logarithmic indices. The figures associated with the analysis results were slightly modified in consideration of the energy market situation in Korea and considering the data treatment when the original IO table was composed by the BOK. One of the reasons for this is that Liquefied Natural Gas (LNG) and district heating were introduced in Korea in 1987 and 1992, respectively. As a result, in the analysis of the corresponding period, the effects of the market entry of these two fuels on the sector 4 (Gas) and sector 8 (Heat) were highly significant, overwhelming the other sectors (Figure 5.7). Another reason was related to a data-processing problem that arose due to the exclusion of energy sources according to changes in the data collection method. The BOK changed their data collection method such that no self-consumption of Naphtha appeared in the preparation of the IO table for 2005, which was published in 2008. Consequently, the effect of the market exit of sector-7 (Naphtha) during the corresponding period was exaggerated.

In this study, to specify the excessive incremental effects due to the entry of new energy sources and the exit of old sources, the letter ‘m’ in parentheses was appended in the right graphs in Figure 5.7. Here, the analyses were carried out under the assumption that the input values of the most recent period were continuously maintained.

Decomposition analysis of the changes in GHG emissions based on the E-IO tables for the years 1985 and 2005 revealed that the energy use effect (D_{tot}) had a positive impact while the technology change effect (D_{tech}) showed a negative impact. The social factor effect (D_{soc}) varied according to the sector (Figures 5.6 and 5.7).

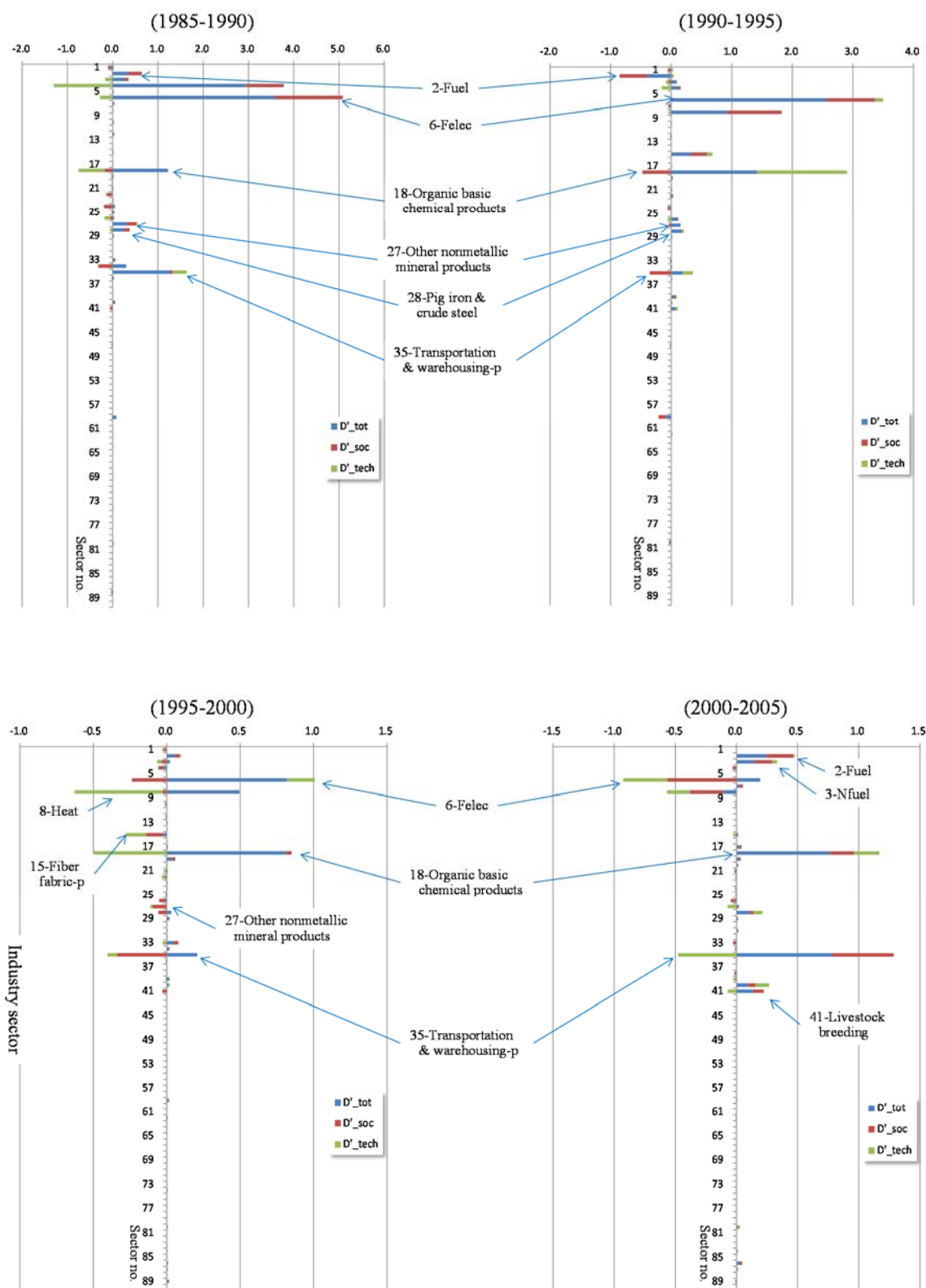


Figure 5.6 Decomposition results of the direct GHG emissions for three effects.

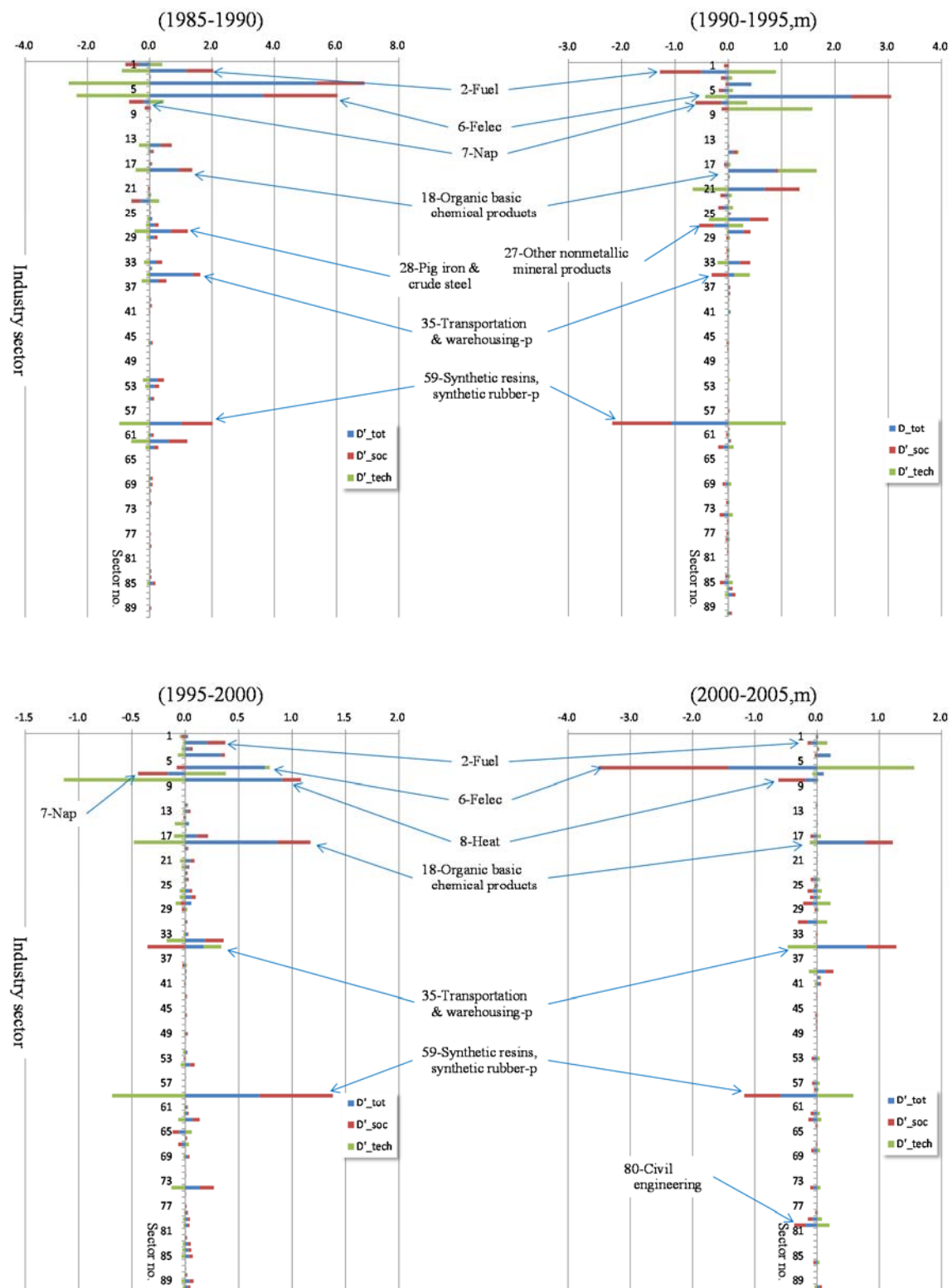


Figure 5.7 Decomposition results of the embodied GHG emissions for three effects.

Korea has considered climate change issues in its energy policy since the middle of the 1990s. An explanation of the three periods will be helpful for the reader to understand the situation in Korea. An increase in D_{tot} was the greatest factor in the increase of the GHG emissions, whereas D_{tech} had a growing negative effect from the “Phase II”. However, as time passed, the magnitudes of the three decomposition effects have become smaller. This shows that changes in the GHG emissions according to energy use in the intermediate sectors of Korea have gradually stabilized. Moreover, it was demonstrated that this phenomenon has been more prominent in the energy sectors. In addition, the relative importance of D_{tot} , which has had a considerable impact on the “Phase I”, has tended to decrease gradually, whereas the relative levels of importance of D_{soc} and D_{tech} increased during the “Phase III”.

Hereafter, the results for each period are described separately.

Phase I (1985-1995): D_{tot} provided the largest contribution to the increase of GHG emissions, but it was found that the contribution of D_{soc} was comparable in sectors #2 (Fuel), #4 (Gas), and #8 (Heat). In sectors #18 (Organic basic chemical products) and #35 (Transportation & warehousing-p), a significant impact of D_{tech} (upper side graphs in Figures 5.6 and 5.7) was evident. The D_{tech} effect changed its contribution from negative to positive, while the D_{tot} effect was found to follow the reverse path.

Phase II (1995-2000): D_{tot} had the greatest effect on the increase in GHG emissions as a whole and D_{soc} followed, although it did in fact contribute to a negative impact in a few sectors. The impact of D_{tech} increased so as to offset the impact of D_{tot} in both the direct emission and total emission matrices of sectors #8 (Heat), #18 (Organic basic chemical products) and #59 (Transportation & warehousing-p) (corresponding period in Figures 5.6 and 5.7).

Phase III (2000-2005): D_{tot} generally showed a positive impact due to the increase in GHG emissions. D_{soc} and D_{tech} showed negative as well as positive impacts across the various sectors. In particular, the D_{tot} effect on sector 8 (Heat) turned negative from positive in the prior period due to the decrease in energy consumption in the direct emission matrix. In the total emission matrix, sector 8 (Heat), sector 59 (Transportation & warehousing-2p), and sector 80 (Civil Engineering) indicated negative indices because the negative values of D_{tot} and D_{soc} had surpassed the positive D_{tech} (corresponding period in Figures 5.6 and 5.7).

5.3.3 Decomposition analysis of the aggregated data

According to Eqs. (5.8)-(5.10), Figure 5.8 shows the results of the decomposition analysis applied to the aggregated energy consumption data of Korea. The left and right sides of the figure represent the decomposition results of the direct GHG emission matrix and that of the total emission matrix, respectively. In terms of the direct GHG emission of Korea, during the first (85-90) and second terms (90-95), all effects increased. However, in the third (95-00) and fourth terms (00-05), the other effects except D_{tech} tended to decrease gradually. D_{tech} presented a small increase during the second (90-95) and third (95-00) terms. A slight change in the increase of D_{tech} during these periods was attributed to the maintenance of the low prices of fossil fuels worldwide in an era before the efforts to address the climate change issues began in Korea.

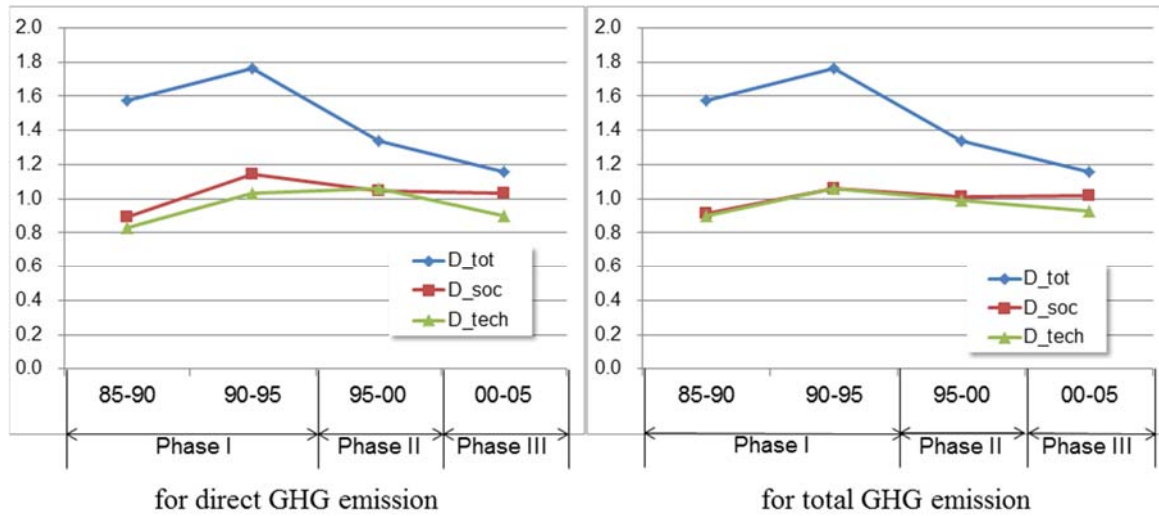


Figure 5.8 Decomposition results for the aggregated changes in GHG emissions.

On the other hand, all effects tended to decrease gradually after 1995 in an analysis of the total emissions. In addition, the contribution level of the three effects was found to have decreased as a whole. The largest contribution to the increase of GHG emissions (an effect having a value greater than 1 on the Y-axis) was D_{tot} ; next was D_{soc} (the D_{soc} effect had almost no contribution to the changes in GHG emissions). In contrast, D_{tech} , which implies a GHG emission coefficient, contributed to a decrease in GHG emissions except during the second term (90-95) (an effect having a value smaller than 1 on the Y-axis).

5.4 Conclusion

The implementation of an aggregated GHG policy can diminish policy efficiency because the GHG emission characteristics are highly distinctive of each sector in an economy. Recently, therefore, a sectoral approach has been considered as required for the energy and environment policy. In this context, an IDA is also useful for understanding the characteristics of each sector and for preventing the illusion that either an increase (+) or a decrease (-) of GHG emissions is solely measured as a net value itself.

With respect to the energy and environment analysis of Korean economy, the following policy usefulness was obtained in the present work: By applying the IDA to the predetermined sectors obtained by the E-IO analysis instead of the national aggregate data, the homogeneity of the rearranged sectors under consideration was enhanced and a more realistic feature was made possible in the real world. In addition, through the analysis capability of the direct effect and the induced effect emphasized as an advantage of the IO analysis, both the direct and the induced GHG emissions can be measured.

Korea's energy and environment policy goals have the following priority. First, the aggregate demand saving is the top priority policy, because most of consumed energy relies on imports from foreign countries. Next, while undergoing two rounds of oil shocks in the 1970s, Korea's energy policy is concerned on the industry. As a part of the policy, the amounts of energy consumption in energy consuming industries are strictly managed. Finally, as importance of the international agreement on global warming, reducing GHG emissions in the energy sector was pursued. The policy resulted in the replacement of coal and oil with natural gas and nuclear energy emphasized as a low-carbon energy source.

The results of the IDA have well explained the performance of these national energy and environment policy. First, D_{tot} was the biggest effect on the increase of GHG emissions in Korea. Total effect does not impact on the GHG emissions reduction because economic policy pursuing economic development through heavy and chemical industries overwhelmed national energy and environment policy. Thus, the reduction of energy consumption or GHG emissions by improving energy intensity was not achieved. Accordingly, the sectors with (+) value had a large number throughout analysis period. However, sectors having (-) value increased rapidly in non-energy groups and the number of the sectors with (-) value were more than double especially after the phase II in effect on D_{soc} . Number of sectors having (-) value were relatively larger than sectors having (+) but constant in energy intensive group, and number of sector having (-) was increased rapidly in energy less-intensive group. It shows that proportion of industry-specific energy use is rapidly diminishing in energy less-intensive group. In other words, it means national energy and GHG abatement policy influenced a lot in energy less-intensive group. Finally, similar temporal change of D_{soc} was observed in D_{tech} . It means that the pattern of D_{tech} was similar to that of D_{soc} because the low-carbon energy, including nuclear and hydro, was introduced through electric power generation. The actual proportion of low-carbon energy has increased from 35.2% in 1985 to 41.7% in 2005.

This study is useful from the following viewpoints of national energy and environmental policy:

- As the relative importance of the energy sector is significant in the national low-carbon policy, it can take charge of the most basic role during the integration of policies and provide a quantitative foundation. Such a foundation is necessary for the establishment of an integrated policy in the form of useful information regarding any correlation among economic activities, energy consumption, and GHG emissions.
- As regards a long-term and future-oriented approach toward an energy policy, it can easily provide a basis in consistent, long-term and detailed data.
- It can provide a quantitative analysis foundation for a “Sectoral Approach”, the important issue that emerged during the post-Kyoto negotiations and that increased in importance with the adoption of the Bali Road Map in 2008.
- It is easy to minimize the time gap of economic data collection and policy planning through E-IO analysis which can generate useful information with sequential and consistent analysis, including economic activities, energy use, GHG emission and the verification of causes.
- The methodology and analytical techniques developed in this study can be easily applied to other problems if the relevant data is available.

In this study, changes in GHG emissions were decomposed into total energy consumption (D_{tot}), the sectoral structure of energy consumption (D_{soc}) and GHG emission according to

energy use (D_{tech}) with the IDA method. Despite the advantages of this method, some limitations arose during the processes of the Divisia decomposition analysis.

- First, the three effects affecting GHG emissions can be measured quantitatively, but there are limits to directly explore causal factors related to the current status. It serves insufficient information for situational and experiential estimation and for interpreting effects of GHG emissions changes.
- Second, variations in the decomposition results showed unstable shift pattern unexpectedly. Usually quite stable changes of D_{soc} or D_{tech} can be expected in decomposition analysis. In this analysis, however, the amplitude of the variation was larger. Changes in these unstable trends can be explained in several ways. It implies that IDA may have a limitation in setting of the effects to be analyzed. Another finding gives inspiration on the effect selection and weighting measure as an average for the following researcher.
- Third, in a long-term energy analysis, the market entry of new energy sources and the exit of existing energy sources are common. In this situation, the use of the Divisia analysis and the LMDI index results in extraordinary values for specific sectors. In such cases, inconveniences in the observation of analysis results arise.

Nonetheless, we can conclude that IDA is a convenient decomposition tool for energy analyses and that it can provide useful pointers for national energy and environment policies when supplemented by other methods such as the econometric methods.

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Chapter 6. Empirical Test of Index Decomposition Analysis

In this chapter, the acceptability was verified based on the validity of the analysis results counted from the whole procedure of the energy input-output analysis and decomposition analysis of two sectors: ‘organic basic chemical products’ and ‘cement and concrete products’. An empirical test was performed using changes in energy consumption, production, process improvements, and new facilities. Although the results showed unstable fluctuations of the Divisia index decomposition analysis, it was verified that the entire procedure can provide a useful decision-making basis in understanding each industry's energy consumption and GHG emissions.

6.1 Adequacy of the estimated energy data

The adequacy of the primary energy input calculated in this study from 1985 to 2000 has been verified through Table 4.2. The estimated energy consumptions from the E-IO table for 2005 are as follows (Table 6.1). KEEI in column (b) indicates Korea’s official energy data [1].

Table 6.1 Comparison of the primary energy consumption

(units: kTOE)			
Energy source	E-IO (a)	KEEI (b)	a/b (%)
Coal	56,045	54,788	102
Crude petroleum	123,395	101,526	122
Natural gas	31,775	30,355	105
Water power generation	450	1,297	35
Thermal & self-power generation	19,912	47,970	42
Atomic power generation	12,628	36,695	34

These estimations are acceptable as measures for Korea's energy and environmental policies because the sectoral price variation of the energy sources is small and the average national values for the energy sources were used.

6.2 Analysis of social and technical impacts on energy use and GHG emissions

6.2.1 Overall trends of plotting patterns from 1985 to 2005

Figure 4.7 shows the relationship between total energy and GHG emissions intensities for a 96-industry classification. Figure 6.1, in contrast, plots the direct energy intensities vs. GHG emission intensities for a 90-sector classification. The red lines and attached figures indicate the regression line passing through the origin and their slopes for three sectoral groups. The X-axis

and Y-axis represent the energy consumption intensity and GHG emissions intensity, respectively.

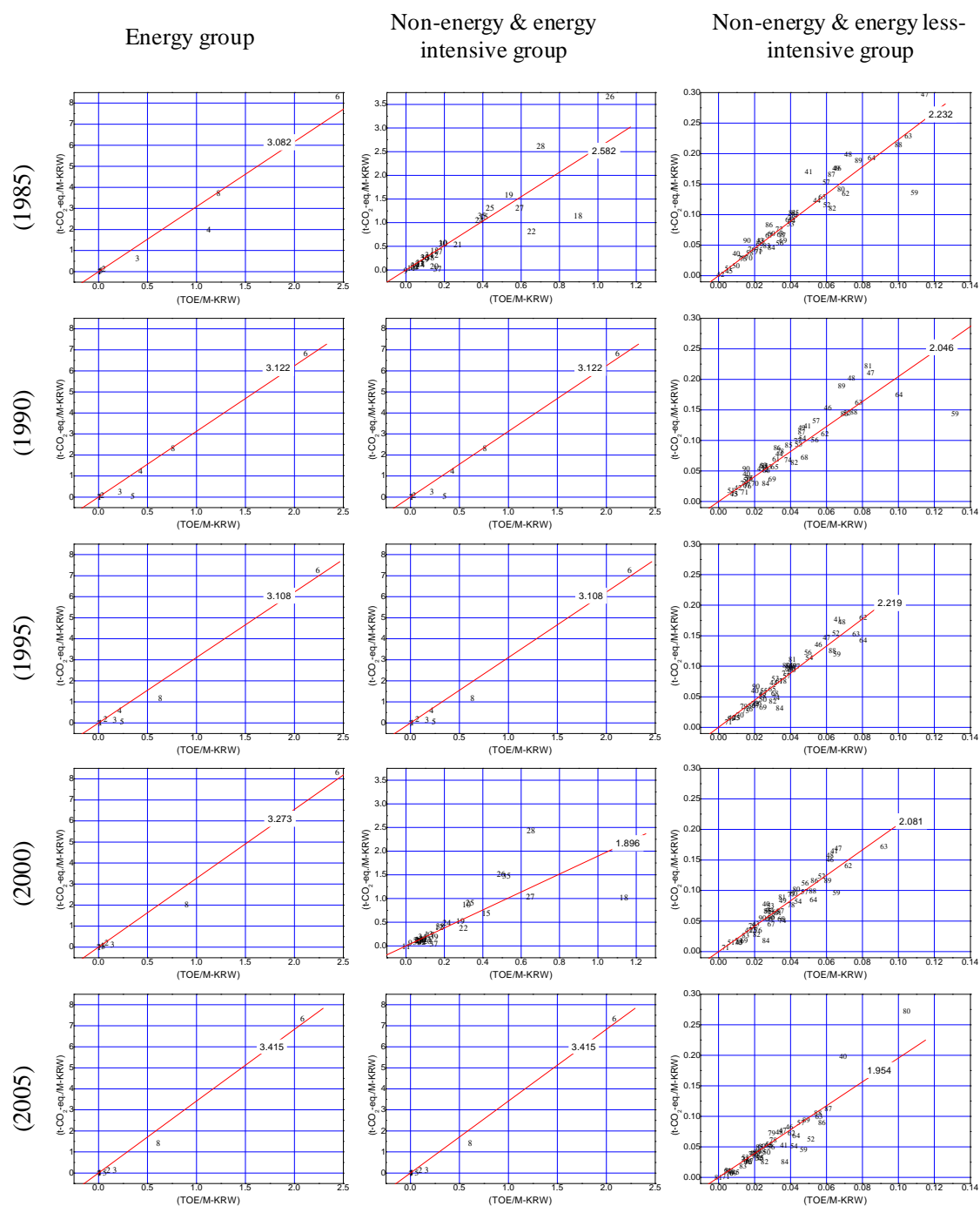


Figure 6.1 Temporal distribution changes in direct intensities in each group.

The changes in the slope of this line signify the rate of change in GHG emissions intensity with respect to a change in the energy intensity. Therefore, a decreasing slope over time means that the corresponding sector's GHG emissions intensity has improved. In contrast, an increasing slope implies that the GHG emission intensity has been degraded.

Slopes of direct intensities for the energy group (sector 1 - 8) over time increased, from 3.082 in 1985, to 3.415 in 2005. This indicates deterioration in the GHG emissions tendency. In contrast, the non-energy and energy intensive group (sector 9 - 39) and non-energy and energy less-intensive group (sector 40 - 90) had the slope of an improved pattern. In addition, the Euclidean distance from the origin to each sector has a message in the policy developer. The distance from the original point represents a worsening state of energy and/or GHG emissions intensities of the sector in question, whereas getting close to the original point represents an improving state.

6.2.2 Selection of distinct sector

In an effort to analyze the results of energy use and GHG emissions, as well as the implications of industrial policies, distinct sectors were selected from non-energy and energy intensive groups that have relatively high percentages of energy use (sector 9-39). The sectors have a relatively higher proportion of energy use and are analyzed in terms of socio- and technical- impacts on their energy use and GHG emissions.

The specific sectors are selected as follows based on the temporal distribution patterns of the sectors and IDA results, as shown in Figures 6.2 and 6.3:

- trending upward to the right: sector-18, organic basic chemical products including petrochemical basic products, petrochemical intermediate products, coal chemicals, and other basic organic chemicals, and;
- trending downward to the left: sector-26, cement & concrete products including cement, ready mixed concrete, concrete blocks, bricks, and other concrete products.

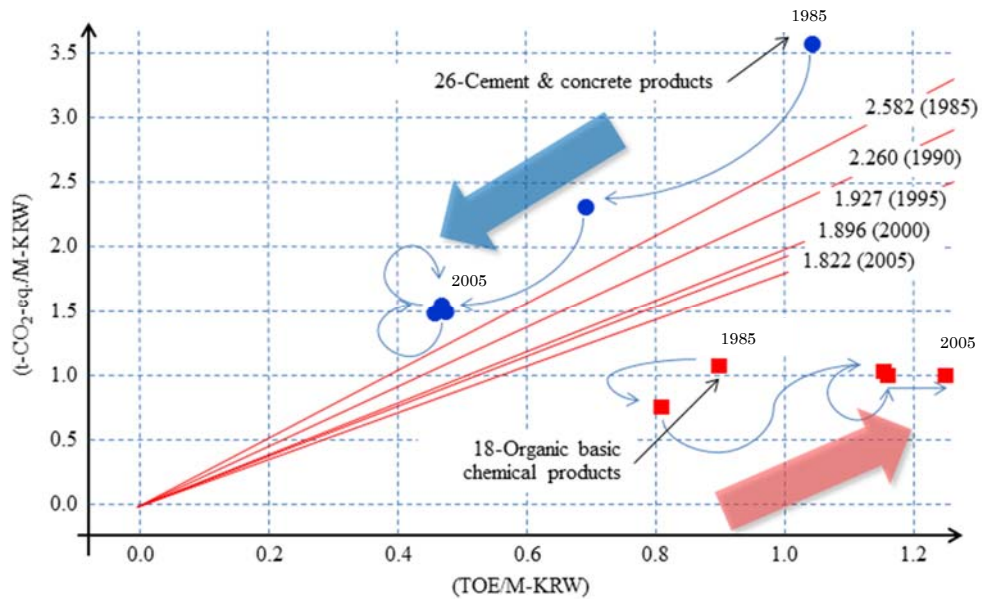
The red lines in Figure 6.2 have the same meaning as mentioned before. They show that the GHG emissions from the sectors in the non-energy and energy intensive groups are improving. Sector-18 shows an improvement by moving toward the origin from 1985 to 1990, and thereafter gradually moving away from the origin by 2005. In contrast, sector-26 has continuously shifted toward the origin since 1985.

The estimators generated from the E-IO analysis were compared with the actual data during the analysis period for validation of the E-IO analysis (Table 6.2).

Table 6.2 Comparison of energy consumption (kTOE) of 2 sectors

		1985	1990	1995	2000	2005
Sector-18	E-IO(a)	3,229,919	6,552,538	19,653,790	29,667,193	40,111,151
	KEEI(b)	5,088,000	9,839,000	22,838,000	35,641,000	42,488,000
	a/b(%)	63	67	86	83	94
Sector-26	E-IO(a)	2,975,174	3,531,667	4,839,842	4,260,451	4,577,354
	KEEI(b)	1,926,847	3,055,314	3,868,469	3,946,645	3,492,593
	a/b(%)	154	116	125	108	131

Adequate KEEI (b) data of Sector-26 was not found. Thus, the data were partly extrapolated based on the reports of Korean energy consumption surveys [2]. It was created by a bottom-up process and was the results of a sample survey of a sector. Therefore, the value does not indicate the overall energy consumption of the sector. These estimates showed relatively acceptable results. The overall gap between the estimated value and the actual data is based on the difference in the aggregation of components. The reason for the estimation error in the two sectors is the difference in the aggregate sectors in general.



Remarks: Regression lines indicate relations for entire sectors. Blue circles and red squares are for two specific sectors in energy intensive group.

Figure 6.2 Temporal changes in the relationship between energy and GHG emission intensities.

D_{soc} denotes the energy use structure in Korean industries. It can represent that how much an industry or sector has been activated compared to other sectors in the economy. D_{tech}

shows the GHG emission intensity, which depends on the specific technologies relevant to energy use in the corresponding sector. It will be able to estimate the relative level of process innovation and use of low-carbon energy technology.

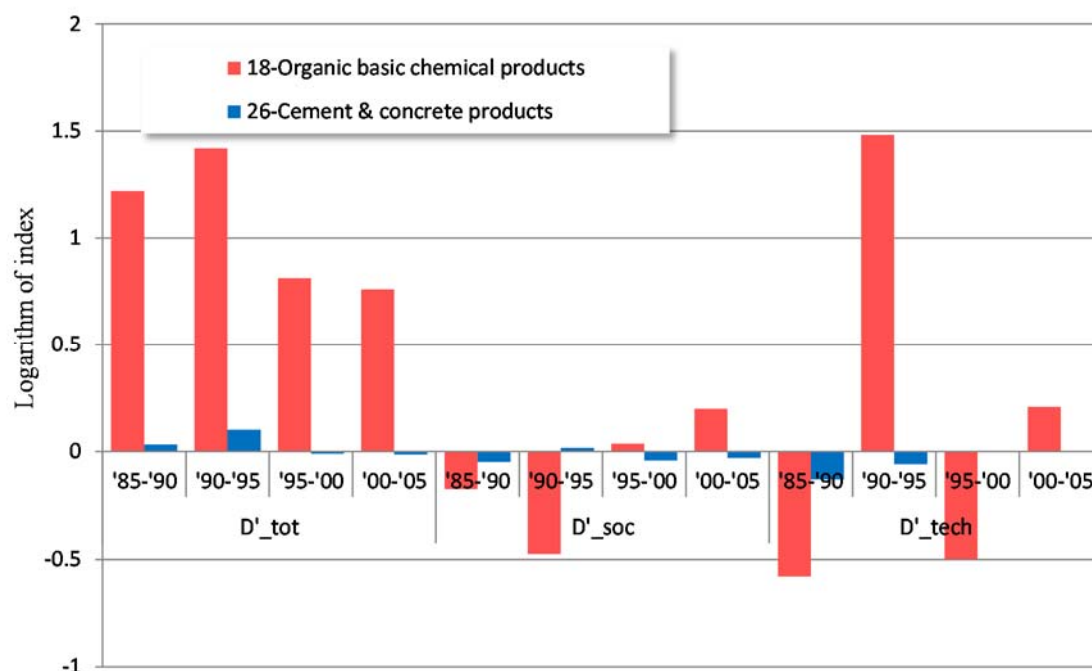


Figure 6.3 IDA results for the two sectors in energy intensive group.

Figure 6.3 demonstrates that even if the distribution pattern of a sector shows a continual improvement over time, the results of decomposition analysis can produce different values. For example, in terms of the overall pattern of sector-26 has been improved during 1990 and 1995, but in terms of the IDA the D_{tot} and D_{soc} effects have contributed to an increase (+), while D_{tech} contributed to a decrease (-).

The IDA results shown in Figure 6.3 are difficult to analyze for statistical trends. This is too small a number of observations to obtain a statistical significance and stable estimation along the time series analysis. The reason for the IDA results will be analyzed empirically in the next section through an investigation of the circumstance changes of 2 specific industries.

6.3 Empirical analysis of two specific sectors

6.3.1 Comprehensive analysis of sector-18

Sector-18 (organic basic chemical products) is an energy-intensive industry in a highly competitive global economy. This industry uses the most energy to extract the intermediate goods such as ethylene, propylene and benzene from the raw materials such as naphtha. In addition, more energy is consumed in processing intermediate goods, the production of

ammonia used as fertilizer, and the production of caustic soda for synthetic detergent. On average, the share of energy in total production costs is about 9%. For some petrochemicals, it rises up to 75%. Therefore, the chemical industry has already invested in energy efficiency improvement over many decades.

The petrochemical industry has a close relationship with cutting-edge new industries, such as the IT industry. High-tech industrial development needs the support of the petrochemical industry and requires the expanding role of the sector. The petrochemical industry is gradually expanding its scope through continuous research, and is developing high value-added intermediate goods through the high-performance engineering of plastics and fine chemicals.

GHG emissions from sector-18 have been increasing owing to the growth in demand for industrial gas, which is required for heavy electrical equipment and semiconductor production.

Because the proportion of GHG emissions from this sector is more than 6% of the national total emissions in South Korea, the national GHG reduction policy must include this sector [3]. The raw material of the petrochemical industry is naphtha, which has high carbon content. After oxygen combines with carbon, GHGs are emitted. Unlike other industries, the overall GHG emissions during manufacturing process of the petrochemical industry accounts for more than 10% of all GHG inventory in sector-18.

Under the circumstances of the South Korea statistical account, if the oil refinery industry is added to the petrochemical industry, the proportion of sector-18 will be more than 5% of the energy use in South Korea. The energy efficiency of Korean sector-18 was recorded as the world's highest as a part of the whole process. However, the cost proportion of naphtha is 60%, and that of energy is more than 10% of the whole cost in South Korea. Thus, the competitive factors in this industry will depend on the energy efficiency.

Over time, the distribution of sector-18 shows a trend upward and to the right (Figure 6.2). The deteriorating pattern of this sector can be explained in a real economy in terms of the social and technical aspects.

- Among the steep growth of the IT industry, the total energy consumption was increased. In the social aspect, sector-18's proportion of energy consumption to the national total is maintained at 1%. This implies that energy-saving efforts were not made.
- For the total effect, the annual average growth rate of the final energy consumption was 6.7% during the analysis period. In particular, the rates of Gas and Naphtha were 15.6% and 11.2%, respectively. Such high growth rates of the two sectors have influenced a positive direction in D_{tot} .
- For the social effect, because of an entry barrier, few companies were managing their business for domestic demand until 1995. Through an improvement in the process, companies have been working to improve their energy efficiency. The energy consumption per unit of production has been improved by 3% per year during this period. A large-scale petrochemical complex was built in 1991. The movement of raw materials and intermediate goods is reduced by integrating related industries, where the energy efficiency has been significantly improved as a result. The development of new technologies and processes has not been carried out since the currency crisis of 1997, and large-scale capital investment has been reduced. Therefore, in this industry, improvements in energy efficiency have stagnated.

Ethylene production capacity stood at 5.75 million tons in 2005, from 5.02 million tons in 1999. The trends of these changes in sector-18 affect the share of energy consumption. This is a pattern that matches the changing social effect.

- For the technical effect, 6 new companies entered the market owing to deregulations during the early 1990s. The new companies had a similar pattern of energy use, and their GHG emissions have increased rapidly. These efforts mean that the profile can lead to an increase in GHG emissions directly in the event of the entry of a new comer of this industry or a delayed improvement in energy efficiency. Changes in the structure of the energy consumption in this industry are needed. This means that a conversion effort is required to lower the carbon containing energy sources.
- In addition, the development of high value-added products in the industry is also an important factor because the common denominator of the energy intensity and GHG emissions intensity is the volume of the added value, which means that if a further reduction of energy use and/or GHG emissions is difficult, higher value-added products should be developed. As an example, while South Korea ranks fourth in the world in the scale of production of the total amount of universal resin in polymeric materials, the technology level in polymer materials for cutting-edge industries remained at 45% compared to the United States, and at 60% compared to Europe and Japan.

6.3.2 Comprehensive analysis of sector-26

Sector-26 (cement and concrete products) is considered to be one of the most important building materials around the world. It is mainly used for the production of concrete. Concrete is a mixture of inert mineral aggregates, e.g., sand, gravel, crushed stones, and cement. Cement consumption and production are closely related to construction, and therefore to general economic activities. Cement is one of the most highly produced materials in the world.

Three production steps are distinguished in the description of cement production:

- Preparing raw materials: mixing/homogenizing, grinding, and preheating (drying) produces the raw meal.
- Burning raw meal to form a cement clinker in a kiln: the components of the raw meal react at high temperatures (900 - 1500 °C) in the pre-calcliner and in the rotary kiln, to give cement clinker.
- Finish grinding the clinker and mixing with additives: after cooling the clinker is ground together with additives.

Cement production is a highly energy-intensive sector. It is well known that the energy consumption of the cement industry is estimated to be about 2% of the global primary energy consumption, or almost 5% of the total global industrial energy consumption. Owing to the dominant use of carbon intensive fuels, e.g., coal, in clinker making, the cement industry is also a major emitter of GHG emissions. In addition to energy consumption, the clinker making process also emits GHGs from the calcining process. The cement industry contributes 5% of total global CO₂ emissions.

The major source of its CO₂ emissions is the chemical reaction during the production process. However, this study focuses on the CO₂ emissions associated with the energy use of the cement industry. The main energy sources in the cement manufacturing process are B-C oil, coal, electricity, and alternative energies (alternative fuel and raw materials). Among them, heavy oil and bituminous coal are used in direct heating (primarily kiln fuel), and electricity is used for a power supply for crushing and mixing. Other sources are used for the heating, lighting, etc., but the quantity is negligible.

The GHG emissions in cement manufacturing come directly from the combustion of fossil fuels and from calcining the limestone in the raw mix. An indirect and significantly smaller source of GHG emissions is from the consumption of electricity, assuming that the electricity is generated from fossil fuels. Roughly half of the emitted GHG originates from the fuel and half originates from the conversion of the raw material.

This sector changed production facilities from a wet to dry process to improve the energy efficiency. This process substitution can reduce the energy consumption by up to 50%. Energy costs account for 20–40% of the cement production cost. The energy consumption required to produce one ton of clinker is 5.9 – 6.7GJ for the wet process and only 2.9 – 4.6GJ for the dry process.

Over time, the distribution of sector-26 shows a trend upward and to the right (Figure 6.2). The deteriorating pattern of this sector can be explained in the real economy in terms of the social and technical aspects.

- For the total effect, the annual average growth rate of the final energy consumption was 6.7% during the analysis period. In particular, the rates of Nfuel and electricity were 17.6% and 9.9%, respectively. Such high growth rates of the two sectors have influenced a positive direction in D_{tot} .
- For the social effect, the process improvement influenced D_{soc} to reduce the GHG emissions in general. However, D_{soc} has increased during 1990–1995. The construction of 2 million housing units along the government's expansion policy in 1988 led to a surge in cement production with a 10.4% annual average growth rate. Negative values showed that process improvements effect was discharged, and has been influenced from the decline in cement consumption since 1995. Cement production is reduced 4.7 million tons in 2005 from 5.5 million tons in 1995. This means an annual average growth rate of -1.5%.
- In contrast, for the technical aspect, process improvements have an influence on the energy efficiency and alternative energy. During 1985–1995, switching from coal to electricity affected the change in D_{tech} . Therefore, the process improvement was a negative factor during this period. During the economic downturn of sector-26 since 1995, a change of D_{tech} was rarely seen. This is because the energy alternation and process improvement were faced with limitations. Sweeping relaxation of the regulation on waste usage can be a breakthrough of the limitations of these improvements. Currently, the use of waste fuels is highly regulated in South Korea. Thus, the proportion of waste fuel in the cement sector has remained at 2.5% since the 1990s. This is significantly lower than the levels of Germany (38%), France (33%) and Japan (16%) [4]. Deregulation will lead to an increase in the utilization of waste fuel instead of coal, and it is expected to have additional reduction of GHG emissions from the cement sector.

6.4 Conclusion

This holistic approach is useful in an understanding of the industry's energy and GHG footprint.

The following efforts are required to improve the aforementioned two sectors:

- One is the reduction of energy consumption through energy conservation and an efficiency improvement of sector-18. Even if domestic petrochemical production companies produce the same product, there are large differences in the energy intensity of each company. The intensity of a company was 70% higher than that of the most efficient company in ethylene production, while another company showed a 150% higher intensity than the most efficient company during benzene production. Even if they have different operating conditions, it is evident that the process improvement for energy reduction is urgent. NCC (Naphtha Cracking Center) was evaluated to be the most energy consuming process. Therefore, the most effective process for the reduction of GHG emissions would be the NCC process.
- The other is that high-value added products should be sought. This exploitation should cover the efforts to convert low-price raw materials into high-value added products, as well as to create new higher value-added products.

A temporal plot of the relationship between energy and GHG emission intensities makes it easier to determine improvement opportunities where a large effect can be expected with less effort. As shown in Figure 6.2, a huge improvement in the cement industry occurred between 1985 and 1995. After that, it is difficult to find significant improvements through 2005. This means that technological innovation is needed to overcome the limits of gradual improvement in the cement industry from now on. Emissions of GHG can be reduced by the following efforts:

- improvement of the energy efficiency of the process;
- shift to a more energy efficient process (e.g., from a (semi) wet to (semi) dry process);
- replacement of high carbon fuels by low carbon fuels;
- application of the low clinker cements (increasing the ratio of additives to cement), that is, blended cements;
- application of alternative cements (mineral polymers);
- removal of GHG from the flue gases.

In an industry-specific analysis like this, the limitation of an IDA analysis should be recognized. In an IDA analysis, a slight change in data can excessively influence the result of a decomposition analysis, resulting in an unstable tendency. Therefore, it is necessary to study the ways to stabilize this unstable tendency, such as the selection of weighted values.

These results can then be the basis of an atlas map to support a sectoral policy in South Korea. For example, energy savings in a sector having a greater D_{soc} have to be emphasized, while a sector having a greater D_{tech} shall be encouraged to transition into a clean process using less carbon containing energy. National targets for energy and GHG reductions can be achieved effectively and efficiently using a sectoral approach. Therefore, it is necessary to introduce this method into a national policy as soon as possible.

References

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- [2] KEEI, Energy Consumption Survey of 1983-2010, 1984-2011.
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Chapter 7. Conclusion

Because Korea is not an Annex I country in the Kyoto Protocol, it does not have GHG reduction obligations. Nevertheless, Korea wishes to participate in the worldwide efforts to mitigate GHG emissions because its trade volume ranks 9th in the world with a high dependence on foreign goods. Korea's proportion of imports and GHG emissions comprise more than 25% and 80% of the energy sector, respectively. Therefore, in order to minimize the contraction of economic activities while maximizing the reduction of GHG emissions, effective policy-making is necessary in the energy sector.

This study established a model that quantitatively examines the relationship between the economic activity, energy use, and GHG emissions with analyzing the time series changes of the decomposed factors of GHG emissions. The analysis model produced hybrid unit E-IO tables from 1985 to 2005 with 90×90 sectors. The sectors present in the tables, including the previously 96×96 sectorized E-IO tables from 1985 to 2000, were aligned using decomposition and combination for similar sectors in terms of energy use based on the benchmark IO table of 2005. The 2005 benchmark table contains 403 categories announced by the BOK. Then, the decomposition of time series change factors was performed using the index decomposition analysis (IDA) method. The achievements along the E-IO analysis path were prepared as results and were discussed in each chapter.

The following were accomplished in this study.

- Previous studies have been conducted based on the energy consumption survey conducted by KEEI every three years. Therefore, it is inevitable that the industry classification standards and survey depth are not consistent with the monetary IO reported by the BOK. Thus, studies were not able to follow as much detail as the BOK classified. Unlike previous studies using 20,000 samples, this study only used data from the BOK and can obtain results that are as detailed as the original BOK classifications.
- The established E-IO model analyzed the characteristics of each energy source as used in each sector of the Korean economy, as well as the emissions characteristics of three GHGs (CO₂, CH₄, and N₂O). The compatibility of the estimated emissions was verified in a follow up comparison with those in the national communication report prepared for UNFCCC.
- The presented requirements of the energy conservation condition and Hawkins-Simon condition were reviewed during the E-IO model development process. In addition, the compatibility of Dietzenbacher and Stage's statement that "a hybrid approach may induce arbitrary results that depend on the chosen units, rather than on changes in the economic structure" was verified as part of the IDA process.
- Finally, the structural analysis of specific sectors for empirical analyses of industries was attempted.

The E-IO analysis used in this study has the following additional advantages.

- The method suggested in this study can analyze the energy use and GHG emission characteristics for each sector, as can be achieved in the conventional IO analysis. Moreover, the relationship analyses of the emission and intensity of each GHG species

and the source-wise energy use for each industry are possible. Relationship analyses, such as the induced effect and linkage effect, between industries are also possible. The implementation of the E-IO analysis has an important function in policy effectiveness such as the GHG emissions quota system, which was effective in Korea from 2012.

- A metric model that describes climate change must include not only the direct emissions of pollution sources but also the induced indirect emissions. An assessment that incorporates the indirect emissions should be considered carefully during discussions for a new climate change regime, such as in the post-Kyoto Protocol era, that encourages the participation of developing countries, because it is difficult to expect a real worldwide or nationwide decrease in pollutant emissions if countries or industries simply transfer emissions from one country or industry to another. Moreover, not only does a national climate change countermeasure decrease pollutant emissions, but it also directly affects the sustainable growth of an economy. Because the enforcing of environmental policies has a profound effect on economic progress, a metric analysis of the relationship between the economy, energy, and environment is essential.
- The analysis results are useful for establishing a national energy-GHG policy on a sectorial basis considering the characteristics of each industry, which is recommended rather than an aggregated policy that would be subjected to the nation as a whole. That is, this signifies the possibility of policy planning that reflects the total energy use and/or GHG emission effect, including the induced effects rather than only the direct effects. In addition, depending on whether the priority of the policy goals is energy consumption reduction or GHG emission reduction, reliable quantitative data can be provided to establish an appropriate industry-specific policy basis.
- It can provide a tool such as a geological atlas, which enables the exploration of an organic relationship between the economy, energy, and environment. Based on the E-IO table's recorded economic activities, there is a great advantage in analyzing the relationship between the economy and energy. This is also expected to provide reliable results if it is supplemented with the results obtained from international organizations such as the Intergovernmental Panel on Climate Change (IPCC).

In order to improve the accuracy of the E-IO analysis model used in this study, the following requirements should be satisfied.

- The national statistics system must be unified. In order to produce highly reliable E-IO tables through the collection and verification of national energy statistics, the GHG emissions statistics and economic statistics must be consistent and the differences between the sector classification standards and data accounting standards should be harmonized.
- An E-IO table with much higher sectorial resolution must be developed, such as the BOK's basic IO table [27] with a classification system using 403 sectors. More detailed sector classification is required in order to establish a more sophisticated and useful energy-environment policy using the analysis results.
- Energy sources must be classified in more detail, particularly according to the final energy use pattern. In this study, the energy sources were grouped into 14 types through verification with the energy balance sheet listed in KEEI [1], but a more detailed sector classification is required in order to practically support Korea's energy policy. For example, in order to implement a more effective analysis of climate change from the transportation sector, fuels such as gasoline, diesel, kerosene, bunkers, LPG, and LNG should be ungrouped and each should be set as an independent sector.

- In this study, a single weighted average price was used for each energy source when composing the E-IO tables; however, in reality, the same energy source is priced differently from sector to sector. For example, electricity tariffs vary across consumers and a differential pricing system is being implemented to foster specific industries.

This study can lead to the following future works.

- The energy and GHG emissions analysis in this study can be applied to various hybrid industry-related analyses according to the changes in the subject of policy establishment characteristics. For example, it allows to the additional assessment of global and/or regional environmental factors, such as the acidification potential and ozone layer depletion potential, while minimizing the additional work required in order to analyze the effects of environmental pollution on international trade.
- The effective achievement of a common global goal could be accomplished through a cross-national comparative analysis. In particular, when promoting efficiency lessons gained from the experiences of developed nations in energy-environment policies as best practice, it can be expected that sharing the efficient policy can lead to low energy use or GHG emissions reduction without inhibiting the economic growth in developing nations.
- Furthermore, the relocation or transfer effect analysis of the cross-national energy consumption or GHG emissions is possible through a multi-sector economy linkage analysis. This can provide meaningful information for the establishment of global energy and GHG policies.
- Finally, the expansion of the time span to predict future values through the application of conventional inter-industry analysis methods such as MEM or RAS is necessary. This allows visual simulations of the effects that can be expected with the implementation of policies, which can provide motivation for decision makers to become more aware of the importance of implementing the policy in focus.

The valuable results of the energy input-output analyses proposed in this paper suggest that the proposed model will be a useful analytical tool for the establishment of national energy and GHG policies.

Appendices

- Appendix 1. Sector Classifications**
- Appendix 2. Sectoral Energy Intensity**
- Appendix 3. Sectoral CO₂ Emission Intensity by Energy Use**
- Appendix 4. Sectoral CH₄ Emission Intensity by Energy Use**
- Appendix 5. Sectoral N₂O Emission Intensity by Energy Use**
- Appendix 6. Sectoral GHG Emission Intensity by Energy Use**
- Appendix 7. Decomposition Results of the Direct GHG Emissions for Three Effects**
- Appendix 8. Decomposition Results of the Embodied GHG Emissions for Three Effects**

Appendix 1. Sector Classifications

✧ Classification method according to energy input

- Final energy input ratio of sector i

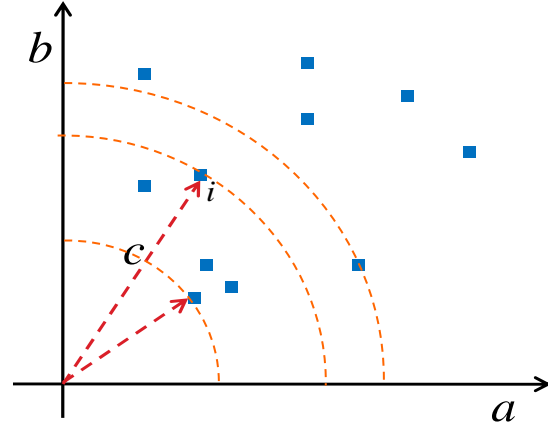
$$a_i = \frac{\text{Final energy input for sector } i}{\text{Total input for sector } i}$$

- Proportion of final energy input of sector i

$$b_i = \frac{\text{Final energy input for sector } i}{\text{Total energy input to entire economy}}$$

- Distance of Sector i

$$c_i = \sqrt{a_i^2 + b_i^2}$$



✂ In this study, less energy intensive group was composed of the sectors of the bottom 30% of the cumulative distance distribution

✧ Relationship between various classification

no.	E-IO (96)	no.	E-IO (90)	no.	M-IO (404)
1	Coal	1	Coal	0031	Anthracite
				0032	Bituminous coal
2	Crude petroleum	2	Fuel	0033	Crude petroleum
3	Natural gas	4	Gas	0034	Natural gas
4	Coal products	1	Coal	0137	Coal briquettes
				0138	Coke and other coal products
5	Naphtha	7	Nap	0139	Naphtha
6	Gasoline	2	Fuel	0140	Gasoline
7	Fuel Oil	2	Fuel	0141	Jet oil
				0142	Kerosene
				0143	Light oil
				0144	Heavy oil
				0145	Liquefied petroleum gas
8	Misc. Petroleum refinery products	3	Nfuel	0146	Lubricants
				0147	Misc. Petroleum refinery products

9	Water power generation	5	Lelec	0305	Water power generation
10	Thermal & self-power generation	6	Felec	0306	Thermal power generation
				0308	Self-Power generation
11	Atomic power generation	5	Lelec	0307	Atomic power generation
12	Town Gas	4	Gas	0309	Manufactured gas supply
13	Heat	8	Heat	0310	Steam and hot water supply
14	woods			0026	Misc. Forestry products
15	Crops-p	9	Crops-p	0002	Barley
				0003	Wheat
				0004	Miscellaneous cereals
16	Fishery products	10	Fishery products	0027	Marine fishing
				0028	Fresh water fishing
				0029	Marine culture
				0030	Fresh water culture
17	Metallic minerals	11	Metallic minerals	0035	Iron ores
				0036	Copper ores
				0037	Lead and zinc ores
				0038	Misc. Nonferrous metal ores
18	Nonmetallic minerals	12	Nonmetallic minerals	0039	Sand and gravel
				0040	Crushed and broken stone
				0041	Other bulk stones
				0042	Limestone
				0043	Materials for ceramics
				0044	Crude salt
				0045	Misc. Nonmetallic minerals
19	Sugar and starches	13	Sugar and starches	0060	Raw sugar
				0061	Refined sugar
				0062	Starches
				0063	Glucose, glucose syrup and maltose
20	Fiber yarn	14	Fiber yarn	0087	Silk yarn
				0088	Woolen yarn
				0089	Cotton yarn
				0090	Hempen yarn
				0091	Regenerated fiber yarn
				0092	Synthetic fiber yarn
				0093	Thread and other fiber yarns
21	Fiber fabrics-p	15	Fiber fabrics-p	0101	Knitted fabrics
				0102	Fiber bleaching and dyeing
22	Wood and wooden products-p	16	Wood and wooden products-p	0118	Lumber
				0119	Plywood

23	Pulp and paper-p	17	Pulp and paper-p	0120	Reconstituted and densified wood
				0124	Pulp
				0125	Newsprint
				0126	Printing paper
				0127	Other raw paper and paperboard
24	Organic basic chemical products	18	Organic basic chemical products	0148	Petrochemical basic products
				0149	Petrochemical intermediate products
				0150	Coal chemicals
				0151	Other basic organic chemicals
25	Inorganic basic chemical products	19	Inorganic basic chemical products	0152	Industrial gases
				0153	Basic inorganic chemicals
26	Synthetic resins and synthetic rubber-p	20	Synthetic resins and synthetic rubber-p	0155	Synthetic rubber
27	Chemical fibers	21	Chemical fibers	0156	Regenerated cellulose fibers
				0157	Synthetic fibers
28	Fertilizers and agricultural chemicals-p	22	Fertilizers and agricultural chemicals-p	0158	Nitrogen compounds
				0159	Fertilizers
29	Other chemical products	23	Other chemical products	0164	Dyes, pigments, and tanning materials
				0165	Paints, varnishes, and allied products
				0166	Printing ink
				0167	Adhesives, gelatin and sealants
				0168	Explosives and fireworks products
				0169	Recording media for electronic equipments
				0170	Photographic chemical products
				0171	Misc. Chemical products
30	Glass products	24	Glass products	0178	Sheet glass and primary glass products
				0179	Industrial glass products
				0180	Household glass products and others
31	Pottery and clay products	25	Pottery and clay products	0181	Industrial pottery products
				0182	Pottery, china and earthenware for home use
				0183	Clay refractories
				0184	Clay products for construction
32	Cement and concrete products	26	Cement and concrete products	0185	Cement
				0186	Ready mixed concrete
				0187	Concrete blocks, bricks, and other concrete products

33	Other nonmetallic mineral products	27	Other nonmetallic mineral products	0188	Lime, gypsum, and plaster products
				0189	Cut stone & stone products
				0190	Asbestos and mineral wool products
				0191	Abrasives
				0192	Asphalts
				0193	Misc. Nonmetallic minerals products
34	Pig iron and crude steel	28	Pig iron and crude steel	0194	Pig iron
				0195	Ferroalloys
				0196	Steel ingots and semifinished products
35	Primary iron and steel products	29	Primary iron and steel products	0197	Steel rods and bars
				0198	Section steel
				0199	Rails and wires
				0200	Hot rolled steel plates and sheets
				0201	Steel pipe and tubes, except foundry iron pipe and tubes
				0202	Cold rolled steel sheet, strip, and bars
				0203	Iron foundries and foundry iron pipe and tubes
				0204	Forgings
				0205	Coated steel plates
				0206	Misc. Primary iron and steel products
36	Nonferrous metal ingots and primary nonferrous metal products-p	30	Nonferrous metal ingots and primary nonferrous metal products-p	0207	Copper ingots
				0208	Aluminum ingots
				0209	Lead and zinc ingots
				0210	Gold and silver ingots
				0211	Other nonferrous metal ingots
37	Fabricated metal products-p	31	Fabricated metal products-p	0219	Handtools
				0220	Bolts, nuts, screws, rivets, and washers
				0221	Fabricated wire products
				0222	Fastening metal products
				0223	Treatment and coating of metals
				0224	Household metallic utensils
				0225	Misc. Fabricated metal products
38	Machinery of and general purpose-p	32	Machinery and equipment of general purpose-p	0227	Valves
				0228	Bearings, gears, gearing and driving elements

39	Wholesale and retail trade	33	Wholesale and retail trade	0329	Wholesale trade
				0330	Retail trade
40	Eating and drinking places, and hotels and other lodging places	34	Eating and drinking places, and hotels and other lodging places	0331	Eating and drinking places
				0332	Hotels and other lodging places
41	Transportation and warehousing-p	35	Transportation and warehousing-p	0333	Railroad passenger transportation
				0334	Railroad freight transportation
				0335	Road passenger transportation
				0336	Road freight transportation
				0337	Coastal and inland water transportation
				0338	Deep sea transportation
				0339	Air transportation
				0340	Services incidental to road transportation
				0341	Services incidental to water transportation
				0342	Airports, flying, fields and airport terminal services
				0343	Cargo loading or unloading operations
				0344	Warehousing and storage
42	Public administration and defense	36	Public administration and defense	0372	Public government
				0373	Local government
43	Gas and water supply	37	Gas and water supply	0311	Water supply
44	Medical and health services, and social security-p	38	Medical and health services, and social security-p	0386	Sanitary services(public)
				0387	Sanitary services (commercial)
45	Other services-p	39	Other services-p	0396	Motor repair services
				0397	Other personal repair services
				0398	Laundry and cleaning services
				0399	Barber and beauty shops
				0400	Domestic services
				0401	Other personal services
46	Crops-p	40	Crops-p	0001	Unmilled rice
				0005	Vegetables
				0006	Fruits
				0007	Pulses
				0008	Potatoes
				0009	Oleaginous crops

				0010	Cultivated medicinal herbs
				0011	Other edible crops
				0012	Cotton and hemp
				0013	Leaf tobacco
				0014	Ornamental floriculture
				0015	Natural rubber
				0016	Seeds and seedlings
				0017	Other Inedible crops
47	Livestock breeding	41	Livestock breeding	0018	Dairy farming
				0019	Beef cattle
				0020	Swine
				0021	Poultry and eggs
				0022	Other livestock breeding
48	Forestry products	42	Forestry products	0023	Forest planting and conservation
				0024	Raw timber
				0025	Edible forestry products
49	Meat and dairy products	43	Meat and dairy products	0046	Slaughtering and meat processing
				0047	Poultry slaughtering and processing
				0048	Prepared meat products
				0049	Milk
				0050	Milk products
				0051	Ice cream
50	Processed products	44	Processed products	0052	Fish fillets and fish cake products
	seafood		seafood		
				0053	Canned seafood
				0054	Frozen fish and seafood
				0055	Salted, dried and smoked seafood
				0056	Misc. Processed seafood
51	Polished grains, flour and milled cereals	45	Polished grains, flour and milled cereals	0057	Polished rice
				0058	Polished barley
				0059	Flour and cereal preparations
				0064	Bakery products
52	Bakery and confectionery products, noodles	46	Bakery and confectionery products, noodles		
				0065	Confectionery products
				0066	Noodles
53	Seasonings and fats and oils	47	Seasonings and fats and oils	0067	Refined salt
				0068	Fermented seasonings
				0069	Other seasonings
				0070	Soy sauce ad bean paste

				0071	Animal and marine fats and oils
				0072	Vegetable fats and oils, and processed edible refined oil
				0073	Canned or cured fruits and vegetables
54	Canned or cured fruits and vegetables and misc. food preparations	48	Canned or cured fruits and vegetables and misc. food preparations		
				0074	Coffee and tea
				0075	Ginseng products
				0076	Malt and yeast
				0077	Bean curd
				0078	Miscellaneous foodstuffs
				0079	Ethyl alcohol for beverages
				0080	Distilled spirits (soju)
				0081	Beer
				0082	Other liquors
				0083	Soft drinks
				0084	Spring water and manufactured ice
55	Beverages	49	Beverages	0085	Prepared livestock feeds
56	Prepared livestock feeds	50	Prepared livestock feeds	0086	Tobacco products
57	Tobacco products	51	Tobacco products	0094	Silk fabrics
58	Fiber yarn-p	52	Fiber yarn-p	0095	Woolen fabrics
				0096	Cotton fabrics
				0097	Hempen fabrics
				0098	Regenerated fiber fabrics
				0099	Synthetic fiber fabrics
				0100	Other fiber fabrics
59	Wearing apparels and apparel accessories	53	Wearing apparels and apparel accessories	0103	Knitted wearing apparels
				0104	Knitted clothing accessories
				0105	Textile wearing apparels
				0106	Other clothing accessories
				0107	Leather wearing apparels
				0108	Fur wearing apparels
60	Other fabricated textile products	54	Other fabricated textile products	0109	Textile products
				0110	Misc. Textile products
				0111	Cordage, rope, and fishing nets
61	Leather and fur products	55	Leather and fur products	0112	Leather
				0113	Fur
				0114	Luggage and handbags
				0115	Leather footwear
				0116	Textile footwear and other shoes

62	Wood and wooden products-p	56	Wood and wooden products-p	0117	Other leather products
				0121	Wooden products for construction
				0122	Wooden containers
				0123	Other wooden products
63	Pulp and paper-p	57	Pulp and paper-p	0128	Corrugated paper and solid fiber boxes
				0129	Paper containers
				0130	Stationery paper and office paper
				0131	Sanitary paper products
				0132	Other paper products
				0133	Newspapers
64	Printing, publishing and reproduction of recorded media	58	Printing, publishing and reproduction of recorded media		
				0134	Publishing
				0135	Printing
				0136	Publishing and reproduction of recorded media
				0154	Synthetic resins
65	Synthetic resins and synthetic rubber-p	59	Synthetic resins and synthetic rubber-p		
66	Fertilizers and agricultural chemicals-p	60	Fertilizers and agricultural chemicals-p	0160	Pesticides and other agricultural chemicals
67	Drugs, cosmetics, and soap	61	Drugs, cosmetics, and soap		
				0161	Medicaments
				0162	Cosmetics and dentifrices
				0163	Soap and detergents
68	Plastic products	62	Plastic products	0172	Primary plastic products
				0173	Industrial plastic products
				0174	Household articles of plastic material
69	Rubber products	63	Rubber products	0175	Tires and tubes
				0176	Industrial rubber products
				0177	Misc. Rubber products
70	Nonferrous metal ingots and primary nonferrous metal products-p	64	Nonferrous metal ingots and primary nonferrous metal products-p	0212	Primary copper products
				0213	Primary aluminum products
				0214	Other nonferrous metal casting and forgings, and primary nonferrous metals
71	Fabricated metal products-p	65	Fabricated metal products-p	0215	Metal products for construction
				0216	Metal products for structure
				0217	Metal tanks and reservoirs for equipment

72	Machinery and equipment of general purpose-p	66	Machinery and equipment of general purpose-p	0218	Metal cans, barrels, and drums
				0226	Internal combustion engines and turbines
				0229	Conveyors and conveying equipment
				0230	Air-conditioning equipment and industrial refrigeration equipment
				0231	Boiler
				0232	Heating apparatus and cooking appliances
				0233	Pumps and compressors
				0234	Filtering or purifying machinery for liquid and gases
				0235	Misc. Machinery and equipment of general purpose
73	Machinery and equipment of special purpose	67	Machinery and equipment of special purpose	0236	Metal cutting type machine tools
				0237	Metal forming machine tools
				0238	Agricultural implements and machinery
				0239	Construction and mining machinery
				0240	Food processing machinery
				0241	Textile machinery
				0242	Metal molds and industrial patterns
				0243	Printing machinery
				0244	Machinery for manufacturing semiconductors
				0245	Misc. Machinery and equipment of special purpose
74	Electronic machinery, equipment, and supplies	68	Electronic machinery, equipment, and supplies	0246	Motors and generators
				0247	Electric transformers
				0248	Capacitors and rectifiers
				0249	Electric transmission and distribution equipment
				0250	Insulated wires and cables
				0251	Batteries
				0252	Electric lamps and electric lighting fixtures
				0253	Misc. Electric equipment and supplies
75	Electronic components and accessories	69	Electronic components and accessories	0254	Electron tubes
				0255	Flat digital display
				0256	Semiconductor devices
				0257	Integrated circuits

				0258	Electric resistors and storage batteries
				0259	Electric coils, transformers and other inductors
				0260	Printed circuit boards
				0261	Misc. Electronic components
76	Radio, television and communications equipment	70	Radio, television and communications equipment	0262	Television receiving sets
				0263	Video cassette recorders and players
				0264	Electric household audio equipment
				0265	Other audio and visual equipment
				0266	Wire telephone and telegraph equipment
				0267	Radio and television broadcasting and wireless communications equipment
77	Computer and office equipment	71	Computer and office equipment	0268	Computer and peripheral equipment
				0269	Office machines and devices
78	Household electrical appliances	72	Household electrical appliances	0270	Household refrigerators and freezers
				0271	Household laundry equipment
				0272	Electric household fans
				0273	Household electric cooking and heating equipment
				0274	Other household electrical appliances
79	Precision instruments	73	Precision instruments	0275	Medical instruments and supplies
				0276	Industrial automatic regulators
				0277	Measuring and analytical instruments
				0278	Cinematograph cameras and projectors
				0279	Other photographic and optical instruments
				0280	Watches and clocks
80	Motor vehicles	74	Motor vehicles	0281	Passenger automobiles
				0282	Buses and vans
				0283	Trucks
				0284	Motor vehicles with special equipment
				0285	Motor vehicle engines
				0286	Motor vehicle chassis, bodies and parts
				0287	Trailers and containers
81	Ship building and repairing	75	Ship building and repairing	0288	Steel ships
				0289	Other ships
				0290	Ship repairing and ship parts

82	Other transportation equipment	76	Other transportation equipment	0291	Railroad vehicles and parts
				0292	Aircraft and parts
				0293	Motorcycles and parts
				0294	Bicycles and parts and misc. transportation equipment
83	Furniture	77	Furniture	0295	Wood furniture
				0296	Metal furniture
				0297	Other furniture
84	Other manufacturing products	78	Other manufacturing products	0298	Toys and games
				0299	Sporting and athletic goods
				0300	Musical instruments
				0301	Pens, pencils, and other artists' materials
				0302	Jewelry and plated ware
				0303	Models and decorations
				0304	Misc. Manufacturing products
85	Building construction and repair	79	Building construction and repair	0312	Steel concrete residential building construction
				0313	Wooden and other residential building construction
				0314	Steel concrete nonresidential building construction
				0315	Wooden and other nonresidential building construction
				0316	Building repairs
86	Civil Engineering	80	Civil Engineering	0317	Road construction
				0318	Railroad construction
				0319	Subway construction
				0320	Breakwater, pier, and harbor construction
				0321	Airport construction
				0322	Dam, levee, and flood control project construction
				0323	Water main line and drainage project construction
				0324	Land clearing and reclamation, and irrigation project construction
				0325	Land leveling and athletic field construction
				0326	Electric power plant construction
				0327	Communications line construction
				0328	Misc. Construction
87	Transportation and warehousing-p	81	Transportation and warehousing-p	0345	Other services incidental to transportation

88	Communications and broadcasting	82	Communications and broadcasting	0346	Postal services
				0347	Telephone
				0348	High-speed network services
				0349	Value added communication
				0350	Terrestrial broadcasting
				0351	Cable broadcasting
89	Finance and insurance	83	Finance and insurance	0352	Central bank and banking institutions
				0353	Non-bank depository institutions
				0354	Other financial brokerage institutions
				0355	Life insurance
				0356	Casualty insurance
				0357	Services auxiliary to finance and insurance
90	Real estate agencies and rental	84	Real estate agencies and rental	0358	Owner-occupied dwellings (imputed rent)
				0359	Real estate rental
				0360	Real estate agents and managers
91	Business services	85	Business services	0361	Legal and accounting services
				0362	Architectural engineering services
				0363	Other engineering services
				0364	Computer softwares development and supply
				0365	Computer programming, data processing, and other computer related services
				0366	Renting of machinery and goods
				0367	Advertising services
				0368	Information provision services
				0369	Cleaning and disinfection services
				0370	Agriculture and fishing service
				0371	Misc. Business services
92	Educational and research services	86	Educational and research services	0374	School education (public)
				0375	School education (private, non-profit)
				0376	School education (commercial)
				0377	Research institutes(public)
				0378	Research institutes (private, non-profit)
				0379	Research institutes (commercial)
				0380	Research and experiment in enterprise
93	Medical and health services, and social security	87	Medical and health services, and social security	0381	Medical and health services(public)

			0382 Medical and health services (private, non-profit)
			0383 Medical and health services (commercial)
			0384 Social welfare services (public)
			0385 Social welfare services (Private, non-profit)
94 Culture and recreational services	88 Culture and recreational services		0388 Culture services (public)
			0389 Culture services (other)
			0390 Motion picture production and distribution
			0391 Theatrical producers, bands, and entertainers
			0392 Sports organizations and sports facility operation
			0393 Misc. amusement and recreation services
95 Other services	89 Other services		0394 Business associations and professional membership organizations
			0395 Religious, political, labor, and other social organizations
96 Unclassified activities	90 Unclassified activities		0402 Office supplies
			0403 Business consumption expenditures
			0404 Unclassified activities

Appendix 2. Sectoral Energy Intensity

(unit: TOE/million Korean Won in 2000)

sector		Energy intensity (direct)					Energy intensity (total)				
		1985	1990	1995	2000	2005	1985	1990	1995	2000	2005
energy	1 coal	0.0103	0.0162	0.0218	0.0112	0.0114	2.0456	2.0487	2.0420	2.0210	2.0182
	2 fuel	0.0544	0.0409	0.0735	0.0837	0.1020	2.0610	2.0494	2.0867	2.1088	2.1341
	3 nfuel	0.3994	0.2211	0.1693	0.1430	0.1668	2.5676	2.2869	2.2219	2.1908	2.2330
	4 gas	1.1276	0.4310	0.2174	0.0360	0.0092	2.2517	2.4820	2.2398	2.0445	2.0145
	5 lelec	0.0248	0.3507	0.2422	0.0537	0.0669	2.2006	3.0330	2.6673	2.2380	2.2785
	6 felec	2.4418	2.1166	2.2400	2.4401	2.0846	4.6902	4.3663	4.6711	4.5707	3.9503
	7 nap	0.0172	0.0114	0.0065	0.0054	0.0068	1.0193	1.0141	1.0085	1.0073	1.0106
	8 heat	1.2285	0.7635	0.6347	0.9027	0.6105	3.3529	2.2418	2.2481	2.7665	2.1034
non energy and energy intensive	9 Crops-p	0.0004	0.0505	0.0668	0.0245	0.0125	0.0922	0.1624	0.1514	0.0661	0.0374
	10 Fishery products	0.1935	0.3019	0.3245	0.3154	0.2591	0.4373	0.6041	0.7012	0.7024	0.6275
	11 Metallic minerals	0.0289	0.0077	0.0052	0.0014	0.0010	0.0978	0.0248	0.0133	0.0040	0.0027
	12 Nonmetallic minerals	0.1484	0.1943	0.1850	0.1737	0.2128	0.4124	0.4241	0.4464	0.4044	0.5634
	13 Sugar, starches	0.1489	0.1512	0.1115	0.1197	0.0765	0.5031	0.4732	0.3913	0.4428	0.3380
	14 Fiber yarn	0.0759	0.0749	0.0641	0.0734	0.0834	0.8440	0.8448	0.4980	0.6023	0.4975
	15 Fiber fabrics-p	0.4059	0.3003	0.4190	0.4185	0.2658	1.0409	0.7265	1.0924	1.2491	0.8589
	16 Wood, wooden products-p	0.0401	0.0422	0.0496	0.0702	0.0479	0.2191	0.2175	0.2383	0.3056	0.2596
	17 Pulp, paper-p	0.1682	0.1427	0.1196	0.1283	0.1365	0.6651	0.4776	0.4791	0.5519	0.5728
	18 Organic basic chemical products	0.8973	0.8074	1.1499	1.1367	1.2788	2.0281	1.9720	2.5107	2.6067	2.8540
	19 Inorganic basic chemical products	0.5360	0.3490	0.2558	0.2838	0.2567	1.4418	0.9773	0.8265	0.8437	0.7660
	20 Synthetic resins, synthetic rubber-p	0.1485	0.0449	0.0817	0.1112	0.1333	0.9800	0.8076	1.0270	1.1935	1.4412

21	Chemical fibers	0.2703	0.1982	0.1280	0.1128	0.0877	1.7773	1.6767	1.8205	1.7588	1.6255
22	Fertilizers, agricultural chemicals-p	0.6546	0.5510	0.4649	0.2996	0.1543	1.9034	1.5271	1.1669	0.9161	0.5456
23	Other chemical products	0.0710	0.0859	0.0669	0.0725	0.0511	0.6089	0.6366	0.6177	0.6389	0.5490
24	Glass products	0.3827	0.4017	0.2410	0.2125	0.0861	1.0087	0.9242	0.6744	0.6250	0.3038
25	Pottery, clay products	0.4377	0.3971	0.3723	0.3342	0.1867	1.0075	0.8506	0.9111	0.8421	0.5391
26	Cement, concrete products	1.0640	0.6887	0.4891	0.4963	0.4786	1.9131	1.2632	1.2099	1.1720	1.1742
27	Other nonmetallic mineral products	0.5916	0.6835	0.6814	0.6488	0.4668	1.4884	1.4480	1.3019	1.2497	1.0596
28	Pig iron & crude steel	0.7027	0.5989	0.6379	0.6511	0.8383	2.6526	2.3317	2.7253	2.4806	2.6540
29	Primary iron, steel products	0.0977	0.0854	0.0754	0.0810	0.0727	1.4398	1.2105	1.3425	1.2785	1.2301
30	Nonferrous metal ingots, primary nonferrous metal products-p	0.1927	0.1162	0.0800	0.0586	0.0734	0.4911	0.3043	0.2387	0.2005	0.2469
31	Fabricated metal products-p	0.0737	0.0539	0.0845	0.0892	0.1025	0.6518	0.5286	0.5667	0.5038	0.5822
32	Machinery, equipment of general purpose-p	0.0459	0.0304	0.0562	0.0808	0.0499	0.3420	0.2775	0.3207	0.3619	0.0976
33	Wholesale, retail trade	0.0989	0.1010	0.0993	0.0652	0.0708	0.3071	0.2860	0.2966	0.2162	0.2669
34	Eating, drinking places, hotels, other lodging places	0.1212	0.1177	0.0822	0.0865	0.0745	0.3316	0.3522	0.3241	0.3100	0.3012
35	Transportation & warehousing-p	0.3952	0.4881	0.5471	0.5244	0.3912	0.8358	0.9172	1.0970	1.1110	0.9542
36	Public administration, defense	0.0975	0.0868	0.0741	0.0596	0.0369	0.3566	0.3070	0.2733	0.2107	0.1621
37	Gas, water supply	0.1645	0.1357	0.1423	0.1454	0.1512	0.7209	0.4885	0.6013	0.5762	0.6033
38	Medical, health services, social security-p	0.1270	0.2376	0.1898	0.1790	0.0000	0.3498	0.5067	0.4596	0.4726	0.0000
39	Other services-p	0.0468	0.0764	0.1670	0.1467	0.1046	0.1810	0.2336	0.4242	0.3978	0.3522
40	Crops-p	0.0099	0.0155	0.0202	0.0265	0.0693	0.1027	0.1237	0.1445	0.1582	0.2269
41	Livestock breeding	0.0501	0.0494	0.0662	0.0644	0.0363	0.2615	0.3114	0.2829	0.3005	0.3035
42	Forestry products	0.0011	0.0108	0.0076	0.0168	0.0164	0.0401	0.0520	0.0583	0.0915	0.0609
43	Meat, dairy products	0.0231	0.0236	0.0246	0.0207	0.0151	0.2927	0.2936	0.3003	0.2632	0.2476
44	Processed seafood products	0.0547	0.0338	0.0305	0.0288	0.0193	0.4379	0.4854	0.4813	0.4097	0.3480

non energy and energy less intensive	45	Polished grains, flour, milled cereals	0.0059	0.0086	0.0098	0.0116	0.0095	0.1247	0.1589	0.1793	0.1826	0.2437
	46	Bakery, confectionery products, noodles	0.0661	0.0608	0.0555	0.0620	0.0394	0.3916	0.3482	0.3060	0.3410	0.3093
	47	Seasonings, fats and oils	0.1146	0.0846	0.0601	0.0665	0.0357	0.4997	0.3755	0.3163	0.3385	0.2992
	48	Canned or cured fruits, vegetables, misc. food preparations	0.0721	0.0740	0.0686	0.0621	0.0337	0.3144	0.2742	0.2771	0.2657	0.2353
	49	Beverages	0.0654	0.0463	0.0413	0.0357	0.0219	0.3048	0.2400	0.2540	0.2318	0.1996
	50	Prepared livestock feeds	0.0097	0.0157	0.0247	0.0291	0.0268	0.2310	0.2465	0.2395	0.2382	0.3322
	51	Tobacco products	0.0056	0.0070	0.0068	0.0070	0.0052	0.0682	0.0703	0.0556	0.0626	0.0797
	52	Fiber yarn-p	0.0602	0.0713	0.0652	0.0573	0.0513	0.6389	0.6161	0.6921	0.6172	0.5086
	53	Wearing apparels, apparel accessories	0.0400	0.0446	0.0316	0.0289	0.0149	0.5311	0.5055	0.3798	0.3807	0.2186
	54	Other fabricated textile products	0.0407	0.0467	0.0505	0.0443	0.0419	0.5751	0.5386	0.5193	0.5909	0.4539
	55	Leather, fur products	0.0238	0.0254	0.0252	0.0277	0.0229	0.2604	0.2785	0.2679	0.3151	0.3722
	56	Wood, wooden products-p	0.0340	0.0535	0.0497	0.0481	0.0293	0.2648	0.2624	0.3006	0.3211	0.3004
	57	Pulp, paper-p	0.0598	0.0543	0.0379	0.0478	0.0458	0.4793	0.3916	0.3400	0.4460	0.4315
	58	Printing, publishing, reproduction of recorded media	0.0174	0.0168	0.0243	0.0294	0.0282	0.2977	0.2476	0.2601	0.3298	0.3251
	59	Synthetic resins, synthetic rubber-p	0.1089	0.1315	0.0658	0.0655	0.0473	1.2853	1.2567	1.4705	1.5586	1.4990
	60	Fertilizers, agricultural chemicals-p	0.0294	0.0250	0.0409	0.0418	0.0241	0.6511	0.7683	1.0466	1.2172	1.0599
	61	Drugs, cosmetics, soap	0.0392	0.0320	0.0338	0.0331	0.0208	0.4049	0.3486	0.4176	0.3889	0.3108
	62	Plastic products	0.0707	0.0592	0.0805	0.0722	0.0406	0.7813	0.6693	0.8003	0.8482	0.6291
	63	Rubber products	0.1056	0.0780	0.0765	0.0920	0.0558	0.6673	0.5011	0.5211	0.5622	0.5309
	64	Nonferrous metal ingots, primary nonferrous metal products-p	0.0851	0.1003	0.0805	0.0528	0.0432	0.4959	0.3769	0.3326	0.2464	0.2617
	65	Fabricated metal products-p	0.0576	0.0313	0.0298	0.0320	0.0278	0.9043	0.5718	0.6044	0.6183	0.5620
	66	Machinery, equipment of general purpose-p	0.0230	0.0265	0.0218	0.0281	0.0210	0.2628	0.3102	0.2707	0.3046	0.2956
	67	Machinery, equipment of special purpose	0.0281	0.0157	0.0205	0.0293	0.0173	0.2784	0.2012	0.2229	0.2639	0.2075

68	Electronic machinery, equipment, supplies	0.0345	0.0478	0.0314	0.0349	0.0241	0.3269	0.3330	0.2773	0.2622	0.2302
69	Electronic components, accessories	0.0359	0.0298	0.0247	0.0143	0.0083	0.4449	0.3986	0.3061	0.1623	0.0957
70	Radio, television, communications equipment	0.0167	0.0202	0.0119	0.0109	0.0062	0.3764	0.3510	0.2476	0.1634	0.1168
71	Computer, office equipment	0.0221	0.0145	0.0055	0.0039	0.0042	0.3275	0.3573	0.2249	0.1379	0.0667
72	Household electrical appliances	0.0337	0.0257	0.0203	0.0187	0.0147	0.5941	0.4875	0.3559	0.2967	0.2986
73	Precision instruments	0.0138	0.0087	0.0101	0.0114	0.0065	0.1328	0.1106	0.1035	0.1117	0.0967
74	Motor vehicles	0.0419	0.0386	0.0320	0.0356	0.0216	0.4791	0.4547	0.3840	0.4100	0.3319
76	Other transportation equipment	0.0184	0.0161	0.0170	0.0221	0.0165	0.1906	0.1554	0.1456	0.1890	0.1597
77	Furniture	0.0354	0.0439	0.0374	0.0404	0.0187	0.4389	0.3661	0.3626	0.3492	0.2961
78	Other manufacturing products	0.0406	0.0345	0.0358	0.0404	0.0303	0.4305	0.3462	0.3041	0.3308	0.2706
79	Building construction, repair	0.0126	0.0143	0.0140	0.0188	0.0296	0.3010	0.2488	0.3040	0.3380	0.3363
80	Civil Engineering	0.0682	0.0699	0.0377	0.0433	0.1046	0.3928	0.3382	0.3713	0.4001	0.5231
81	Transportation, warehousing-p	0.0410	0.0832	0.0410	0.0354	0.0000	0.1273	0.2140	0.1175	0.1010	0.0000
82	Communications, broadcasting	0.0632	0.0422	0.0301	0.0212	0.0256	0.2295	0.1572	0.1340	0.1269	0.1402
83	Finance, insurance	0.0268	0.0276	0.0186	0.0151	0.0136	0.1511	0.1390	0.1117	0.0885	0.0863
84	Real estate agencies, rental	0.0294	0.0262	0.0340	0.0263	0.0369	0.1321	0.1303	0.1663	0.1181	0.1379
85	Business services	0.0426	0.0390	0.0392	0.0272	0.0228	0.2199	0.1942	0.1725	0.1273	0.1286
86	Educational, research services	0.0281	0.0326	0.0406	0.0534	0.0575	0.0849	0.0977	0.1355	0.1669	0.1938
87	Medical, health services, social security	0.0628	0.0461	0.0432	0.0343	0.0610	0.2371	0.1967	0.2144	0.2324	0.2943
88	Culture, recreational services	0.1001	0.0752	0.0632	0.0523	0.0553	0.3217	0.2524	0.2654	0.2085	0.2046
89	Other services	0.0778	0.0685	0.0390	0.0607	0.0488	0.3515	0.3303	0.2607	0.2827	0.2433
90	Unclassified activities	0.0158	0.0154	0.0208	0.0243	0.0053	0.3128	0.3398	0.3489	0.3523	0.2916

Appendix 3. Sectoral CO₂ Emission Intensity by Energy Use

(unit: t-CO₂/million Korean Won in 2000)

sector		CO ₂ emission intensity (direct)					CO ₂ emission intensity (total)				
		1985	1990	1995	2000	2005	1985	1990	1995	2000	2005
energy	1 coal	0.0214	0.0281	0.0491	0.0221	0.0209	7.9520	7.9176	7.8935	7.8300	7.8218
	2 fuel	0.1557	0.1062	0.2001	0.2113	0.1653	6.0735	5.9949	6.0815	6.0742	5.9883
	3 nfuel	0.6345	0.2712	0.1806	0.1587	0.1559	4.7231	4.1510	4.0347	4.0070	4.0080
	4 gas	1.9817	1.2584	0.6355	0.0902	0.0127	4.9475	6.1149	5.3905	4.7426	4.6580
	5 lelec	0.0661	0.0711	0.0731	0.0526	0.0521	0.5842	2.0766	1.2862	0.5636	0.6415
	6 felec	8.2925	6.8268	7.2572	8.3133	7.3201	12.0753	10.3437	11.4095	11.6669	9.7371
	7 nap	0.0485	0.0296	0.0164	0.0126	0.0099	0.8066	0.7885	0.7739	0.7693	0.7702
	8 heat	3.7350	2.3268	1.1728	2.0152	1.4379	7.1196	3.7570	2.7887	4.3368	2.7024
non energy and energy intensive	9 Crops-p	0.0006	0.1525	0.1997	0.0723	0.0359	0.2169	0.4268	0.4264	0.1809	0.0981
	10 Fishery products	0.5902	0.8875	0.9311	0.8858	0.7073	1.3131	1.7616	2.0116	1.9835	1.7315
	11 Metallic minerals	0.0477	0.0088	0.0114	0.0024	0.0026	0.2599	0.0577	0.0347	0.0100	0.0076
	12 Nonmetallic minerals	0.3363	0.3719	0.4412	0.4072	0.5266	1.1310	1.0086	1.1995	1.0894	1.5364
	13 Sugar, starches	0.4138	0.4218	0.2926	0.2529	0.1165	1.4563	1.3396	1.0831	1.1433	0.8140
	14 Fiber yarn	0.1283	0.1391	0.1235	0.1206	0.0626	2.0890	1.9118	1.1045	1.2944	1.0332
	15 Fiber fabrics-p	1.1302	0.8030	0.9134	0.7033	0.3346	2.9751	1.9712	2.6547	2.8162	1.8081
	16 Wood, wooden products-p	0.0739	0.0853	0.1049	0.1407	0.0608	0.5694	0.5396	0.5892	0.7398	0.5821
	17 Pulp, paper-p	0.4069	0.3379	0.2465	0.2361	0.1590	1.8466	1.2430	1.2235	1.3880	1.2695
	18 Organic basic chemical products	1.1376	0.7931	1.0447	1.0166	0.9971	4.2204	3.8830	4.3363	4.6735	4.6739
	19 Inorganic basic chemical products	1.5778	1.0004	0.6206	0.5293	0.3997	4.4969	2.9000	2.2661	2.0937	1.7215
	20 Synthetic resins, synthetic rubber-p	0.0799	0.0059	0.1062	0.1121	0.0620	2.0343	1.5975	1.8857	2.2755	2.3892
	21 Chemical fibers	0.5534	0.3500	0.2067	0.1384	0.1000	4.2646	3.6562	3.4157	3.3510	2.8597
	22 Fertilizers, agricultural chemicals-p	0.8222	0.6431	0.5383	0.3921	0.1636	4.2771	3.2394	2.3528	2.0023	1.1498
	23 Other chemical products	0.1385	0.1701	0.1218	0.1268	0.0811	1.4506	1.3985	1.2577	1.3042	1.0315

non energy and energy less intensive	24	Glass products	1.0682	1.0669	0.6108	0.4930	0.1981	2.9389	2.5403	1.8260	1.6421	0.7663
	25	Pottery, clay products	1.3159	1.1357	1.0548	0.9133	0.4692	3.0197	2.4077	2.5827	2.3608	1.4297
	26	Cement, concrete products	3.6443	2.2918	1.5190	1.5122	1.5367	6.3167	3.9737	3.6589	3.5316	3.5966
	27	Other nonmetallic mineral products	1.3098	1.1240	1.0737	1.0314	0.6851	3.7916	2.9983	2.6390	2.5823	2.1506
	28	Pig iron & crude steel	2.6203	2.1580	2.3671	2.4231	3.1118	9.5700	8.1471	9.7779	8.9469	9.5604
	29	Primary iron, steel products	0.2400	0.1928	0.1392	0.1121	0.0883	4.9461	3.9979	4.5379	4.2581	4.0505
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.5714	0.3237	0.1830	0.0828	0.1044	1.5196	0.8788	0.6545	0.4974	0.5955
	31	Fabricated metal products-p	0.1538	0.0845	0.1541	0.1615	0.2013	2.0169	1.5487	1.6293	1.3993	1.5778
	32	Machinery, equipment of general purpose-p	0.0942	0.0362	0.0592	0.0817	0.0588	1.0481	0.7948	0.8515	0.8981	0.1889
	33	Wholesale, retail trade	0.2782	0.2635	0.2496	0.1282	0.1302	0.9133	0.7973	0.8107	0.5545	0.6802
	34	Eating, drinking places, hotels, other lodging places	0.3261	0.3248	0.1953	0.2034	0.1659	0.9766	0.9894	0.8613	0.8157	0.7719
	35	Transportation & warehousing-p	1.1563	1.3619	1.5488	1.4708	1.0754	2.4646	2.6029	3.1531	3.1775	2.6852
	36	Public administration, defense	0.2625	0.2258	0.1705	0.1262	0.0665	1.0353	0.8496	0.7321	0.5455	0.4113
	37	Gas, water supply	0.0261	0.0265	0.0528	0.0596	0.0507	1.7447	1.0079	1.3816	1.3342	1.3445
	38	Medical, health services, social security-p	0.2667	0.5508	0.4688	0.4126	0.0000	0.9471	1.3271	1.2477	1.2541	0.0000
	39	Other services-p	0.1100	0.1612	0.2493	0.1939	0.1324	0.5111	0.5940	0.9112	0.8421	0.7605
	40	Crops-p	0.0350	0.0451	0.0591	0.0765	0.1960	0.2592	0.3023	0.3445	0.3859	0.5872
	41	Livestock breeding	0.1630	0.1223	0.1761	0.1643	0.0514	0.7806	0.8246	0.7625	0.7957	0.7465
	42	Forestry products	0.0032	0.0228	0.0166	0.0356	0.0264	0.0962	0.1237	0.1333	0.2196	0.1454
	43	Meat, dairy products	0.0581	0.0546	0.0569	0.0458	0.0294	0.8501	0.7781	0.8025	0.6899	0.6173
	44	Processed seafood products	0.1232	0.0782	0.0724	0.0689	0.0397	1.2684	1.3825	1.3545	1.1329	0.9334
	45	Polished grains, flour, milled cereals	0.0089	0.0130	0.0161	0.0153	0.0085	0.3188	0.3936	0.4397	0.4505	0.6262
	46	Bakery, confectionery products, noodles	0.1754	0.1532	0.1355	0.1508	0.0827	1.0915	0.9187	0.7906	0.8692	0.7641
	47	Seasonings, fats and oils	0.2961	0.2107	0.1467	0.1689	0.0773	1.3704	0.9816	0.8119	0.8694	0.7298
	48	Canned or cured fruits, vegetables, misc. food preparations	0.1986	0.2025	0.1724	0.1574	0.0737	0.8935	0.7488	0.7402	0.7010	0.6006
	49	Beverages	0.1759	0.1213	0.1018	0.0846	0.0430	0.8751	0.6499	0.6806	0.6043	0.4987
	50	Prepared livestock feeds	0.0167	0.0349	0.0463	0.0548	0.0423	0.6164	0.6351	0.6163	0.6058	0.8258

51	Tobacco products	0.0131	0.0181	0.0144	0.0150	0.0118	0.1820	0.1802	0.1385	0.1554	0.1964
52	Fiber yarn-p	0.1166	0.1454	0.1539	0.1237	0.0635	1.6281	1.4676	1.5480	1.3444	1.0617
53	Wearing apparels, apparel accessories	0.0848	0.0947	0.0798	0.0759	0.0328	1.3873	1.2292	0.9132	0.8910	0.4944
54	Other fabricated textile products	0.0911	0.1035	0.1139	0.0828	0.0510	1.4696	1.2735	1.1571	1.2739	0.9380
55	Leather, fur products	0.0560	0.0579	0.0601	0.0666	0.0320	0.6833	0.6777	0.6465	0.7440	0.8599
56	Wood, wooden products-p	0.0540	0.1007	0.1224	0.1128	0.0506	0.7082	0.6568	0.7738	0.8124	0.7104
57	Pulp, paper-p	0.1534	0.1322	0.0844	0.0980	0.0899	1.3300	1.0159	0.8512	1.0947	1.0007
58	Printing, publishing, reproduction of recorded media	0.0377	0.0379	0.0522	0.0583	0.0548	0.8228	0.6414	0.6608	0.8207	0.7646
59	Synthetic resins, synthetic rubber-p	0.1351	0.1421	0.1200	0.0958	0.0465	2.8227	2.4982	2.7058	2.9382	2.5692
60	Fertilizers, agricultural chemicals-p	0.0687	0.0606	0.0938	0.0956	0.0524	1.5057	1.6382	1.9731	2.3399	1.8683
61	Drugs, cosmetics, soap	0.0917	0.0699	0.0763	0.0645	0.0361	1.0765	0.8543	0.9413	0.8711	0.6451
62	Plastic products	0.1351	0.1116	0.1801	0.1407	0.0735	1.8437	1.4524	1.6728	1.7600	1.2125
63	Rubber products	0.2278	0.1624	0.1526	0.1713	0.1006	1.7221	1.1959	1.1676	1.2484	1.0919
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.1932	0.1742	0.1426	0.0852	0.0692	1.4519	0.9514	0.8473	0.6033	0.6285
65	Fabricated metal products-p	0.1291	0.0563	0.0635	0.0656	0.0538	2.9164	1.7512	1.9071	1.9082	1.6862
66	Machinery, equipment of general purpose-p	0.0528	0.0513	0.0399	0.0534	0.0413	0.8158	0.8879	0.7883	0.8571	0.8221
67	Machinery, equipment of special purpose	0.0660	0.0266	0.0356	0.0456	0.0272	0.8639	0.5855	0.6450	0.7381	0.5779
68	Electronic machinery, equipment, supplies	0.0679	0.0731	0.0555	0.0544	0.0425	0.9261	0.8352	0.7083	0.6427	0.5568
69	Electronic components, accessories	0.0586	0.0377	0.0333	0.0178	0.0075	1.2359	1.0114	0.7589	0.3848	0.2160
70	Radio, television, communications equipment	0.0296	0.0296	0.0212	0.0159	0.0080	1.0493	0.8894	0.6314	0.3973	0.2739
71	Computer, office equipment	0.0392	0.0153	0.0098	0.0066	0.0026	0.9108	0.9170	0.5677	0.3328	0.1541
72	Household electrical appliances	0.0764	0.0532	0.0385	0.0357	0.0298	1.6837	1.2725	0.9488	0.7710	0.7167
73	Precision instruments	0.0276	0.0130	0.0159	0.0190	0.0107	0.3722	0.2850	0.2641	0.2773	0.2237
74	Motor vehicles	0.0990	0.0682	0.0485	0.0509	0.0314	1.4566	1.2574	1.0303	1.0586	0.8445
75	Ship building, repairing	0.0423	0.0387	0.0284	0.0353	0.0324	1.4375	1.1831	0.8812	0.8236	1.2295
76	Other transportation equipment	0.0435	0.0255	0.0309	0.0358	0.0261	0.5663	0.4166	0.3889	0.4852	0.4066
77	Furniture	0.0663	0.0990	0.0891	0.0933	0.0383	1.2100	0.9597	0.9390	0.9031	0.7268
78	Other manufacturing products	0.0955	0.0818	0.0766	0.0765	0.0616	1.1411	0.8527	0.7351	0.7762	0.6102

79	Building construction, repair	0.0290	0.0301	0.0351	0.0429	0.0726	0.9334	0.7076	0.8795	0.9387	0.9231
80	Civil Engineering	0.1418	0.1438	0.1013	0.1017	0.2726	1.1279	0.9078	1.0742	1.1328	1.4721
81	Transportation, warehousing-p	0.1030	0.2119	0.1059	0.0890	0.0000	0.3593	0.5822	0.3226	0.2726	0.0000
82	Communications, broadcasting	0.1107	0.0632	0.0426	0.0279	0.0261	0.6169	0.3830	0.3364	0.3149	0.3327
83	Finance, insurance	0.0497	0.0565	0.0365	0.0264	0.0196	0.4157	0.3644	0.2938	0.2259	0.2122
84	Real estate agencies, rental	0.0461	0.0302	0.0317	0.0182	0.0258	0.3636	0.3233	0.4143	0.2857	0.3191
85	Business services	0.1035	0.0926	0.1020	0.0662	0.0500	0.6105	0.5133	0.4643	0.3335	0.3234
86	Educational, research services	0.0831	0.0882	0.0970	0.1165	0.0903	0.2577	0.2740	0.3617	0.4355	0.4662
87	Medical, health services, social security	0.1649	0.1135	0.0997	0.0661	0.1131	0.6711	0.5121	0.5376	0.5573	0.6923
88	Culture, recreational services	0.2146	0.1463	0.1254	0.0997	0.1056	0.8842	0.6383	0.6733	0.5238	0.4982
89	Other services	0.1881	0.1881	0.0976	0.1161	0.0945	1.0086	0.9306	0.7060	0.7154	0.6086
90	Unclassified activities	0.0578	0.0533	0.0679	0.0553	0.0105	0.8988	0.9268	0.9297	0.9001	0.7201

Appendix 4. Sectoral CH₄ Emission Intensity by Energy Use

(unit: kg-CH₄/million Korean Won in 2000)

sector		CH ₄ emission intensity (direct)					CH ₄ emission intensity (total)				
		1985	1990	1995	2000	2005	1985	1990	1995	2000	2005
energy	1 coal	0.0007	0.0012	0.0015	0.0011	0.0007	0.0880	0.0881	0.0873	0.0858	0.0850
	2 fuel	0.0066	0.0057	0.0089	0.0096	0.0129	0.2583	0.2577	0.2614	0.2633	0.2676
	3 nfuel	0.0500	0.0277	0.0211	0.0177	0.0208	0.3212	0.2867	0.2785	0.2744	0.2797
	4 gas	0.1369	0.0496	0.0264	0.0038	0.0005	0.1927	0.1390	0.1125	0.0882	0.0846
	5 lelec	0.0028	0.0034	0.0032	0.0025	0.0024	0.0192	0.0624	0.0380	0.0183	0.0182
	6 felec	0.2069	0.1685	0.1628	0.1366	0.0973	0.3570	0.2890	0.2942	0.2208	0.1438
	7 nap	0.0021	0.0015	0.0007	0.0006	0.0009	0.1278	0.1273	0.1264	0.1263	0.1268
	8 heat	0.1534	0.0873	0.2976	0.1051	0.0609	0.9415	0.5393	1.5196	0.4176	0.3228
non energy and energy intensive	9 Crops-p	0.0002	0.0211	0.0278	0.0102	0.0052	0.1617	0.1342	0.1023	0.0585	0.0364
	10 Fishery products	0.0398	0.0626	0.0673	0.0652	0.0523	0.0868	0.1209	0.1414	0.1397	0.1208
	11 Metallic minerals	0.0017	0.0004	0.0003	0.0001	0.0001	0.0135	0.0034	0.0015	0.0006	0.0003
	12 Nonmetallic minerals	0.0108	0.0146	0.0129	0.0119	0.0155	0.0483	0.0450	0.0488	0.0482	0.0626
	13 Sugar, starches	0.0114	0.0117	0.0082	0.0108	0.0070	0.0509	0.0471	0.0423	0.0623	0.0521
	14 Fiber yarn	0.0039	0.0042	0.0054	0.0045	0.0032	0.1054	0.0943	0.0637	0.0788	0.0751
	15 Fiber fabrics-p	0.0312	0.0231	0.1135	0.0605	0.0344	0.1077	0.0752	0.2252	0.1956	0.1407
	16 Wood, wooden products-p	0.0023	0.0026	0.0031	0.0042	0.0021	0.0274	0.0235	0.0266	0.0389	0.0368
	17 Pulp, paper-p	0.0116	0.0106	0.0075	0.0087	0.0126	0.0756	0.0518	0.0581	0.0822	0.0962
	18 Organic basic chemical products	0.1211	0.0804	0.1124	0.1061	0.1114	0.2549	0.2035	0.2674	0.2764	0.2773
	19 Inorganic basic chemical products	0.1356	0.0852	0.0507	0.0439	0.0377	0.3415	0.2242	0.1657	0.1629	0.1410
	20 Synthetic resins, synthetic rubber-p	0.0246	0.0137	0.0334	0.0145	0.0242	0.1306	0.0967	0.1486	0.1517	0.1718
	21 Chemical fibers	0.0155	0.0101	0.0214	0.0087	0.0060	0.2205	0.1877	0.2194	0.2081	0.1795
	22 Fertilizers, agricultural chemicals-p	0.0526	0.0443	0.0461	0.0256	0.0147	0.2128	0.1538	0.1331	0.1141	0.0710
	23 Other chemical products	0.0070	0.0102	0.0063	0.0070	0.0062	0.0844	0.0779	0.0740	0.0790	0.0653

non energy and energy less intensive	24	Glass products	0.0320	0.0334	0.0180	0.0152	0.0076	0.1101	0.0950	0.0743	0.0789	0.0409
	25	Pottery, clay products	0.0585	0.0377	0.0370	0.0347	0.0191	0.1305	0.0904	0.1063	0.1112	0.0758
	26	Cement, concrete products	0.3824	0.2323	0.1441	0.1419	0.1536	0.5647	0.3411	0.2827	0.2845	0.2891
	27	Other nonmetallic mineral products	0.0937	0.0873	0.0882	0.0786	0.0624	0.2174	0.1851	0.1676	0.1611	0.1420
	28	Pig iron & crude steel	0.2589	0.2096	0.2363	0.2442	0.3239	0.9216	0.7803	0.9860	0.9178	1.0034
	29	Primary iron, steel products	0.0110	0.0090	0.0054	0.0042	0.0045	0.4326	0.3513	0.4240	0.4083	0.3991
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.0544	0.0277	0.0140	0.0047	0.0083	0.1204	0.0670	0.0456	0.0358	0.0505
	31	Fabricated metal products-p	0.0064	0.0041	0.0055	0.0061	0.0082	0.1453	0.1180	0.1190	0.1038	0.1171
	32	Machinery, equipment of general purpose-p	0.0042	0.0018	0.0041	0.0057	0.0038	0.0732	0.0601	0.0657	0.0706	0.0125
	33	Wholesale, retail trade	0.0359	0.0371	0.0357	0.0239	0.0204	0.1210	0.1110	0.1133	0.0835	0.0957
	34	Eating, drinking places, hotels, other lodging places	0.0402	0.0414	0.0259	0.0280	0.0227	0.1263	0.1317	0.1197	0.1129	0.1064
	35	Transportation & warehousing-p	0.1852	0.2295	0.2575	0.2472	0.1834	0.3862	0.4271	0.5155	0.5184	0.4443
	36	Public administration, defense	0.0366	0.0336	0.0254	0.0186	0.0101	0.1426	0.1218	0.1043	0.0766	0.0573
	37	Gas, water supply	0.0039	0.0041	0.0069	0.0079	0.0072	0.2245	0.1299	0.1733	0.1659	0.1618
	38	Medical, health services, social security-p	0.0386	0.0816	0.0669	0.0599	0.0000	0.1308	0.1900	0.1759	0.1758	0.0000
	39	Other services-p	0.0138	0.0272	0.0653	0.0538	0.0365	0.0683	0.0889	0.1689	0.1507	0.1284
	40	Crops-p	0.0972	0.0441	0.0462	0.0548	0.1182	0.2867	0.2312	0.2610	0.3281	0.4564
	41	Livestock breeding	0.3498	0.0437	0.0412	0.0418	0.0477	1.1415	0.5177	0.4145	0.5463	0.7875
	42	Forestry products	0.0002	0.0017	0.0013	0.0026	0.0019	0.0769	0.0730	0.0810	0.1718	0.1536
	43	Meat, dairy products	0.0018	0.0016	0.0017	0.0014	0.0010	0.0468	0.0348	0.0350	0.0333	0.0346
	44	Processed seafood products	0.0038	0.0022	0.0021	0.0020	0.0012	0.0468	0.0483	0.0472	0.0424	0.0385
	45	Polished grains, flour, milled cereals	0.0003	0.0004	0.0005	0.0005	0.0003	0.0173	0.0185	0.0217	0.0244	0.0322
	46	Bakery, confectionery products, noodles	0.0050	0.0046	0.0043	0.0047	0.0027	0.0464	0.0389	0.0346	0.0414	0.0393
	47	Seasonings, fats and oils	0.0136	0.0094	0.0043	0.0053	0.0032	0.0623	0.0440	0.0360	0.0414	0.0394
	48	Canned or cured fruits, vegetables, misc. food preparations	0.0058	0.0057	0.0049	0.0047	0.0022	0.0389	0.0305	0.0317	0.0329	0.0309
	49	Beverages	0.0053	0.0039	0.0029	0.0032	0.0023	0.0365	0.0296	0.0329	0.0330	0.0293
	50	Prepared livestock feeds	0.0005	0.0012	0.0020	0.0020	0.0014	0.0301	0.0280	0.0278	0.0307	0.0418

51	Tobacco products	0.0004	0.0006	0.0004	0.0005	0.0004	0.0090	0.0085	0.0067	0.0083	0.0105
52	Fiber yarn-p	0.0034	0.0043	0.0052	0.0040	0.0022	0.0782	0.0680	0.0950	0.0784	0.0738
53	Wearing apparels, apparel accessories	0.0030	0.0029	0.0029	0.0025	0.0012	0.0664	0.0562	0.0509	0.0472	0.0308
54	Other fabricated textile products	0.0029	0.0034	0.0034	0.0027	0.0020	0.0716	0.0599	0.0640	0.0738	0.0611
55	Leather, fur products	0.0019	0.0019	0.0018	0.0020	0.0018	0.0346	0.0320	0.0322	0.0392	0.0516
56	Wood, wooden products-p	0.0022	0.0033	0.0036	0.0034	0.0016	0.0348	0.0296	0.0329	0.0395	0.0418
57	Pulp, paper-p	0.0053	0.0040	0.0030	0.0033	0.0029	0.0566	0.0433	0.0405	0.0608	0.0619
58	Printing, publishing, reproduction of recorded media	0.0016	0.0013	0.0016	0.0020	0.0021	0.0381	0.0288	0.0307	0.0450	0.0468
59	Synthetic resins, synthetic rubber-p	0.0240	0.0179	0.0044	0.0050	0.0052	0.1747	0.1397	0.1614	0.1776	0.1582
60	Fertilizers, agricultural chemicals-p	0.0024	0.0024	0.0043	0.0032	0.0017	0.0836	0.0843	0.1152	0.1335	0.1078
61	Drugs, cosmetics, soap	0.0030	0.0024	0.0024	0.0021	0.0016	0.0524	0.0407	0.0476	0.0473	0.0372
62	Plastic products	0.0044	0.0050	0.0078	0.0053	0.0027	0.1013	0.0780	0.0935	0.1035	0.0729
63	Rubber products	0.0091	0.0056	0.0052	0.0064	0.0039	0.0955	0.0640	0.0679	0.0729	0.0676
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.0061	0.0071	0.0059	0.0036	0.0038	0.0901	0.0564	0.0492	0.0386	0.0468
65	Fabricated metal products-p	0.0047	0.0019	0.0021	0.0024	0.0023	0.2247	0.1379	0.1593	0.1647	0.1472
66	Machinery, equipment of general purpose-p	0.0022	0.0019	0.0016	0.0022	0.0019	0.0577	0.0616	0.0588	0.0649	0.0641
67	Machinery, equipment of special purpose	0.0031	0.0011	0.0013	0.0018	0.0011	0.0610	0.0424	0.0477	0.0571	0.0457
68	Electronic machinery, equipment, supplies	0.0028	0.0035	0.0024	0.0025	0.0021	0.0565	0.0497	0.0430	0.0426	0.0388
69	Electronic components, accessories	0.0021	0.0018	0.0014	0.0008	0.0006	0.0655	0.0536	0.0424	0.0243	0.0154
70	Radio, television, communications equipment	0.0010	0.0014	0.0010	0.0007	0.0004	0.0569	0.0471	0.0344	0.0245	0.0185
71	Computer, office equipment	0.0017	0.0006	0.0003	0.0003	0.0001	0.0516	0.0512	0.0305	0.0200	0.0106
72	Household electrical appliances	0.0023	0.0024	0.0014	0.0014	0.0017	0.1038	0.0767	0.0598	0.0525	0.0504
73	Precision instruments	0.0016	0.0005	0.0006	0.0007	0.0005	0.0214	0.0156	0.0148	0.0168	0.0148
74	Motor vehicles	0.0041	0.0032	0.0021	0.0024	0.0015	0.0972	0.0860	0.0717	0.0762	0.0632
75	Ship building, repairing	0.0013	0.0014	0.0009	0.0012	0.0012	0.1071	0.0877	0.0661	0.0637	0.1021
76	Other transportation equipment	0.0017	0.0011	0.0013	0.0016	0.0012	0.0363	0.0274	0.0252	0.0328	0.0289
77	Furniture	0.0028	0.0029	0.0026	0.0028	0.0013	0.0702	0.0504	0.0495	0.0543	0.0471
78	Other manufacturing products	0.0043	0.0040	0.0034	0.0037	0.0020	0.0599	0.0446	0.0411	0.0470	0.0370

79	Building construction, repair	0.0011	0.0012	0.0010	0.0016	0.0024	0.0680	0.0479	0.0614	0.0672	0.0661
80	Civil Engineering	0.0062	0.0060	0.0031	0.0035	0.0087	0.0726	0.0562	0.0712	0.0800	0.0923
81	Transportation, warehousing-p	0.0149	0.0322	0.0156	0.0136	0.0000	0.0502	0.0850	0.0463	0.0394	0.0000
82	Communications, broadcasting	0.0152	0.0091	0.0062	0.0045	0.0040	0.0831	0.0535	0.0467	0.0443	0.0450
83	Finance, insurance	0.0070	0.0082	0.0051	0.0052	0.0031	0.0568	0.0512	0.0410	0.0336	0.0293
84	Real estate agencies, rental	0.0063	0.0040	0.0039	0.0025	0.0033	0.0479	0.0433	0.0536	0.0369	0.0391
85	Business services	0.0146	0.0130	0.0147	0.0099	0.0074	0.0862	0.0742	0.0675	0.0483	0.0469
86	Educational, research services	0.0101	0.0114	0.0139	0.0169	0.0169	0.0334	0.0371	0.0514	0.0604	0.0679
87	Medical, health services, social security	0.0218	0.0155	0.0149	0.0103	0.0160	0.0937	0.0750	0.0834	0.0867	0.1033
88	Culture, recreational services	0.0279	0.0199	0.0172	0.0139	0.0136	0.1182	0.0876	0.0956	0.0722	0.0647
89	Other services	0.0242	0.0235	0.0138	0.0326	0.0173	0.1354	0.1261	0.1016	0.1218	0.0900
90	Unclassified activities	0.0066	0.0064	0.0085	0.0099	0.0022	0.1256	0.1326	0.1387	0.1347	0.1078

Appendix 5. Sectoral N₂O Emission Intensity by Energy Use

(unit: kg-N₂O /million Korean Won in 2000)

sector		N ₂ O emission intensity (direct)					N ₂ O emission intensity (total)				
		1985	1990	1995	2000	2005	1985	1990	1995	2000	2005
energy	1 coal	0.0002	0.0004	0.0007	0.0003	0.0003	0.1184	0.1184	0.1183	0.1177	0.1176
	2 fuel	0.0013	0.0011	0.0018	0.0019	0.0025	0.0517	0.0515	0.0523	0.0528	0.0535
	3 nfuel	0.0100	0.0056	0.0042	0.0036	0.0041	0.0646	0.0575	0.0558	0.0550	0.0560
	4 gas	0.0272	0.0097	0.0053	0.0007	0.0001	0.0345	0.0193	0.0142	0.0093	0.0086
	5 lelec	0.0006	0.0008	0.0007	0.0005	0.0005	0.0065	0.0221	0.0138	0.0065	0.0075
	6 felec	0.1008	0.0813	0.0879	0.1141	0.1030	0.1348	0.1082	0.1235	0.1469	0.1236
	7 nap	0.0004	0.0003	0.0001	0.0001	0.0002	0.0256	0.0255	0.0253	0.0253	0.0254
	8 heat	0.0307	0.0216	0.0476	0.0333	0.0214	0.1451	0.0854	0.2218	0.0927	0.0643
non energy and energy intensive	9 Crops-p	0.0000	0.0013	0.0017	0.0006	0.0003	0.0026	0.0042	0.0039	0.0017	0.0010
	10 Fishery products	0.0048	0.0075	0.0081	0.0078	0.0063	0.0104	0.0144	0.0169	0.0166	0.0142
	11 Metallic minerals	0.0004	0.0001	0.0001	0.0000	0.0000	0.0027	0.0006	0.0003	0.0001	0.0001
	12 Nonmetallic minerals	0.0030	0.0043	0.0038	0.0035	0.0046	0.0111	0.0107	0.0112	0.0105	0.0144
	13 Sugar, starches	0.0034	0.0035	0.0025	0.0026	0.0014	0.0131	0.0120	0.0100	0.0122	0.0090
	14 Fiber yarn	0.0011	0.0012	0.0013	0.0011	0.0007	0.0234	0.0215	0.0137	0.0162	0.0129
	15 Fiber fabrics-p	0.0093	0.0068	0.0191	0.0109	0.0055	0.0273	0.0185	0.0410	0.0355	0.0222
	16 Wood, wooden products-p	0.0006	0.0008	0.0009	0.0012	0.0005	0.0061	0.0055	0.0061	0.0081	0.0067
	17 Pulp, paper-p	0.0034	0.0030	0.0022	0.0022	0.0023	0.0177	0.0120	0.0121	0.0152	0.0154
	18 Organic basic chemical products	0.0266	0.0210	0.0302	0.0290	0.0318	0.0587	0.0522	0.0678	0.0696	0.0730
	19 Inorganic basic chemical products	0.0211	0.0134	0.0081	0.0077	0.0066	0.0564	0.0367	0.0276	0.0272	0.0227
	20 Synthetic resins, synthetic rubber-p	0.0044	0.0015	0.0049	0.0024	0.0036	0.0286	0.0219	0.0317	0.0327	0.0377
	21 Chemical fibers	0.0046	0.0030	0.0038	0.0018	0.0012	0.0498	0.0434	0.0506	0.0474	0.0418
	22 Fertilizers, agricultural chemicals-p	0.0155	0.0132	0.0122	0.0070	0.0036	0.0518	0.0396	0.0318	0.0247	0.0144
	23 Other chemical products	0.0018	0.0023	0.0016	0.0017	0.0013	0.0182	0.0177	0.0170	0.0175	0.0145

non energy and energy less intensive	24	Glass products	0.0091	0.0096	0.0053	0.0043	0.0016	0.0271	0.0237	0.0172	0.0163	0.0072
	25	Pottery, clay products	0.0128	0.0100	0.0095	0.0085	0.0041	0.0293	0.0222	0.0246	0.0236	0.0136
	26	Cement, concrete products	0.0548	0.0340	0.0218	0.0216	0.0227	0.0867	0.0533	0.0461	0.0457	0.0462
	27	Other nonmetallic mineral products	0.0189	0.0199	0.0199	0.0183	0.0135	0.0460	0.0417	0.0375	0.0358	0.0299
	28	Pig iron & crude steel	0.0369	0.0301	0.0336	0.0346	0.0455	0.1350	0.1140	0.1416	0.1309	0.1405
	29	Primary iron, steel products	0.0024	0.0019	0.0013	0.0011	0.0009	0.0662	0.0532	0.0627	0.0596	0.0565
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.0080	0.0043	0.0023	0.0010	0.0012	0.0194	0.0109	0.0075	0.0058	0.0068
	31	Fabricated metal products-p	0.0015	0.0010	0.0015	0.0017	0.0019	0.0246	0.0194	0.0198	0.0172	0.0185
	32	Machinery, equipment of general purpose-p	0.0010	0.0005	0.0012	0.0016	0.0010	0.0126	0.0099	0.0112	0.0121	0.0023
	33	Wholesale, retail trade	0.0029	0.0028	0.0022	0.0012	0.0012	0.0096	0.0083	0.0075	0.0056	0.0068
	34	Eating, drinking places, hotels, other lodging places	0.0034	0.0031	0.0015	0.0016	0.0013	0.0105	0.0095	0.0077	0.0075	0.0072
	35	Transportation & warehousing-p	0.0138	0.0171	0.0192	0.0184	0.0136	0.0290	0.0318	0.0381	0.0385	0.0324
	36	Public administration, defense	0.0025	0.0022	0.0015	0.0011	0.0006	0.0105	0.0086	0.0072	0.0054	0.0043
	37	Gas, water supply	0.0003	0.0003	0.0004	0.0004	0.0004	0.0196	0.0109	0.0147	0.0159	0.0163
	38	Medical, health services, social security-p	0.0023	0.0049	0.0040	0.0036	0.0000	0.0093	0.0124	0.0116	0.0123	0.0000
	39	Other services-p	0.0012	0.0018	0.0039	0.0032	0.0020	0.0056	0.0065	0.0110	0.0105	0.0089
	40	Crops-p	0.0005	0.0005	0.0007	0.0009	0.0021	0.0034	0.0037	0.0045	0.0049	0.0069
	41	Livestock breeding	0.0024	0.0015	0.0019	0.0019	0.0016	0.0101	0.0093	0.0085	0.0093	0.0103
	42	Forestry products	0.0000	0.0002	0.0002	0.0003	0.0002	0.0011	0.0013	0.0015	0.0024	0.0016
	43	Meat, dairy products	0.0005	0.0005	0.0005	0.0004	0.0003	0.0093	0.0078	0.0079	0.0071	0.0065
	44	Processed seafood products	0.0011	0.0007	0.0006	0.0006	0.0003	0.0116	0.0125	0.0123	0.0106	0.0089
	45	Polished grains, flour, milled cereals	0.0001	0.0001	0.0001	0.0001	0.0001	0.0037	0.0042	0.0049	0.0051	0.0067
	46	Bakery, confectionery products, noodles	0.0015	0.0013	0.0012	0.0014	0.0008	0.0108	0.0089	0.0079	0.0090	0.0079
	47	Seasonings, fats and oils	0.0031	0.0021	0.0012	0.0014	0.0006	0.0142	0.0100	0.0082	0.0089	0.0074
	48	Canned or cured fruits, vegetables, misc. food preparations	0.0017	0.0017	0.0015	0.0014	0.0006	0.0089	0.0072	0.0072	0.0071	0.0062
	49	Beverages	0.0015	0.0011	0.0009	0.0008	0.0004	0.0084	0.0065	0.0069	0.0065	0.0053
	50	Prepared livestock feeds	0.0001	0.0003	0.0005	0.0005	0.0004	0.0066	0.0065	0.0063	0.0063	0.0085

51	Tobacco products	0.0001	0.0002	0.0001	0.0001	0.0001	0.0020	0.0019	0.0015	0.0017	0.0021
52	Fiber yarn-p	0.0010	0.0013	0.0014	0.0011	0.0006	0.0175	0.0155	0.0202	0.0166	0.0131
53	Wearing apparels, apparel accessories	0.0008	0.0008	0.0008	0.0007	0.0003	0.0147	0.0128	0.0109	0.0101	0.0055
54	Other fabricated textile products	0.0008	0.0010	0.0010	0.0008	0.0004	0.0159	0.0137	0.0142	0.0158	0.0116
55	Leather, fur products	0.0005	0.0005	0.0005	0.0006	0.0005	0.0075	0.0073	0.0072	0.0085	0.0098
56	Wood, wooden products-p	0.0005	0.0009	0.0011	0.0010	0.0005	0.0074	0.0066	0.0077	0.0085	0.0078
57	Pulp, paper-p	0.0014	0.0012	0.0008	0.0009	0.0008	0.0130	0.0100	0.0088	0.0121	0.0112
58	Printing, publishing, reproduction of recorded media	0.0004	0.0003	0.0005	0.0005	0.0005	0.0084	0.0065	0.0066	0.0088	0.0083
59	Synthetic resins, synthetic rubber-p	0.0036	0.0033	0.0012	0.0011	0.0009	0.0379	0.0334	0.0395	0.0419	0.0386
60	Fertilizers, agricultural chemicals-p	0.0006	0.0006	0.0011	0.0009	0.0005	0.0189	0.0206	0.0283	0.0325	0.0272
61	Drugs, cosmetics, soap	0.0008	0.0007	0.0007	0.0006	0.0004	0.0116	0.0093	0.0111	0.0104	0.0080
62	Plastic products	0.0013	0.0012	0.0019	0.0014	0.0006	0.0223	0.0178	0.0216	0.0229	0.0161
63	Rubber products	0.0024	0.0016	0.0015	0.0019	0.0011	0.0199	0.0138	0.0146	0.0154	0.0141
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.0017	0.0021	0.0015	0.0009	0.0006	0.0165	0.0109	0.0090	0.0067	0.0065
65	Fabricated metal products-p	0.0012	0.0005	0.0006	0.0006	0.0004	0.0367	0.0221	0.0247	0.0251	0.0216
66	Machinery, equipment of general purpose-p	0.0005	0.0005	0.0004	0.0006	0.0004	0.0099	0.0107	0.0098	0.0108	0.0101
67	Machinery, equipment of special purpose	0.0007	0.0003	0.0004	0.0005	0.0003	0.0104	0.0072	0.0080	0.0094	0.0071
68	Electronic machinery, equipment, supplies	0.0007	0.0010	0.0006	0.0007	0.0004	0.0107	0.0098	0.0082	0.0078	0.0064
69	Electronic components, accessories	0.0006	0.0005	0.0003	0.0002	0.0001	0.0134	0.0111	0.0083	0.0045	0.0025
70	Radio, television, communications equipment	0.0003	0.0004	0.0002	0.0002	0.0001	0.0115	0.0098	0.0069	0.0046	0.0031
71	Computer, office equipment	0.0004	0.0002	0.0001	0.0001	0.0000	0.0102	0.0102	0.0061	0.0038	0.0018
72	Household electrical appliances	0.0007	0.0006	0.0003	0.0003	0.0002	0.0196	0.0148	0.0110	0.0092	0.0084
73	Precision instruments	0.0003	0.0001	0.0002	0.0002	0.0001	0.0042	0.0031	0.0029	0.0032	0.0026
74	Motor vehicles	0.0010	0.0008	0.0006	0.0007	0.0004	0.0172	0.0152	0.0126	0.0133	0.0103
75	Ship building, repairing	0.0004	0.0004	0.0003	0.0004	0.0003	0.0178	0.0146	0.0110	0.0105	0.0157
76	Other transportation equipment	0.0004	0.0003	0.0004	0.0005	0.0003	0.0066	0.0050	0.0046	0.0059	0.0048
77	Furniture	0.0006	0.0009	0.0008	0.0008	0.0003	0.0138	0.0104	0.0103	0.0104	0.0084
78	Other manufacturing products	0.0010	0.0009	0.0008	0.0008	0.0005	0.0126	0.0095	0.0085	0.0093	0.0071

79	Building construction, repair	0.0003	0.0003	0.0003	0.0004	0.0006	0.0115	0.0085	0.0106	0.0116	0.0110
80	Civil Engineering	0.0017	0.0017	0.0009	0.0010	0.0025	0.0134	0.0108	0.0127	0.0139	0.0167
81	Transportation, warehousing-p	0.0009	0.0322	0.0156	0.0008	0.0000	0.0034	0.0055	0.0030	0.0026	0.0000
82	Communications, broadcasting	0.0010	0.0006	0.0004	0.0003	0.0002	0.0063	0.0039	0.0033	0.0033	0.0035
83	Finance, insurance	0.0004	0.0005	0.0003	0.0002	0.0002	0.0041	0.0034	0.0027	0.0023	0.0022
84	Real estate agencies, rental	0.0004	0.0002	0.0002	0.0001	0.0002	0.0039	0.0033	0.0042	0.0032	0.0034
85	Business services	0.0010	0.0008	0.0009	0.0006	0.0004	0.0062	0.0050	0.0044	0.0033	0.0032
86	Educational, research services	0.0009	0.0009	0.0008	0.0010	0.0008	0.0029	0.0029	0.0034	0.0042	0.0048
87	Medical, health services, social security	0.0016	0.0010	0.0008	0.0005	0.0009	0.0069	0.0050	0.0052	0.0059	0.0070
88	Culture, recreational services	0.0021	0.0013	0.0010	0.0008	0.0007	0.0091	0.0062	0.0064	0.0052	0.0044
89	Other services	0.0019	0.0020	0.0008	0.0012	0.0008	0.0106	0.0096	0.0066	0.0073	0.0059
90	Unclassified activities	0.0009	0.0008	0.0009	0.0007	0.0001	0.0097	0.0096	0.0092	0.0090	0.0073

Appendix 6. Sectoral GHG Emission Intensity by Energy Use

(unit: t-CO₂-eq./million Korean Won in 2000)

sector		CO ₂ -eq. emission intensity (direct)					CO ₂ -eq. emission intensity (total)				
		1985	1990	1995	2000	2005	1985	1990	1995	2000	2005
energy	1 coal	0.0215	0.0283	0.0494	0.0223	0.0210	7.9906	7.9562	7.9320	7.8683	7.8601
	2 fuel	0.1563	0.1066	0.2008	0.2121	0.1663	6.0949	6.0163	6.1032	6.0961	6.0105
	3 nfuel	0.6386	0.2735	0.1824	0.1602	0.1576	4.7498	4.1748	4.0578	4.0299	4.0313
	4 gas	1.9930	1.2625	0.6377	0.0905	0.0127	4.9623	6.1238	5.3973	4.7474	4.6625
	5 lelec	0.0664	0.0714	0.0733	0.0528	0.0523	0.5867	2.0847	1.2913	0.5659	0.6442
	6 felec	8.3281	6.8555	7.2879	8.3515	7.3541	12.1246	10.3833	11.4540		9.7784
	7 nap	0.0487	0.0297	0.0165	0.0126	0.0100	0.8172	0.7991	0.7844	0.7798	0.7807
	8 heat	3.7477	2.3353	1.1938	2.0277	1.4458	7.1844	3.7949	2.8894	4.3743	2.7291
non energy and energy intensive	9 Crops-p	0.0006	0.1533	0.2008	0.0727	0.0361	0.2211	0.4309	0.4298	0.1827	0.0991
	10 Fishery products	0.5926	0.8911	0.9350	0.8896	0.7104	1.3181	1.7686	2.0198	1.9916	1.7385
	11 Metallic minerals	0.0479	0.0088	0.0115	0.0024	0.0026	0.2610	0.0580	0.0348	0.0100	0.0076
	12 Nonmetallic minerals	0.3375	0.3736	0.4427	0.4085	0.5283	1.1355	1.0128	1.2041	1.0937	1.5422
	13 Sugar, starches	0.4151	0.4231	0.2935	0.2539	0.1171	1.4615	1.3443	1.0870	1.1484	0.8179
	14 Fiber yarn	0.1287	0.1396	0.1240	0.1211	0.0629	2.0985	1.9205	1.1101	1.3011	1.0388
	15 Fiber fabrics-p	1.1337	0.8056	0.9217	0.7079	0.3371	2.9858	1.9786	2.6721	2.8313	1.8179
	16 Wood, wooden products-p	0.0741	0.0856	0.1052	0.1412	0.0611	0.5718	0.5418	0.5916	0.7432	0.5849
	17 Pulp, paper-p	0.4081	0.3391	0.2473	0.2370	0.1600	1.8537	1.2479	1.2284	1.3944	1.2762
	18 Organic basic chemical products	1.1484	0.8013	1.0565	1.0279	1.0093	4.2440	3.9034	4.3629	4.7009	4.7024
	19 Inorganic basic chemical products	1.5872	1.0063	0.6242	0.5326	0.4025	4.5215	2.9160	2.2782	2.1055	1.7315
	20 Synthetic resins, synthetic rubber-p	0.0818	0.0066	0.1085	0.1132	0.0636	2.0459	1.6063	1.8987	2.2889	2.4045
	21 Chemical fibers	0.5551	0.3511	0.2083	0.1391	0.1004	4.2847	3.6736	3.4360	3.3700	2.8765
	22 Fertilizers, agricultural chemicals-p	0.8282	0.6481	0.5430	0.3948	0.1650	4.2976	3.2549	2.3655	2.0123	1.1558
	23 Other chemical products	0.1392	0.1710	0.1225	0.1274	0.0817	1.4580	1.4056	1.2645	1.3113	1.0373

non energy and energy less intensive	24	Glass products	1.0716	1.0705	0.6128	0.4947	0.1987	2.9496	2.5497	1.8329	1.6488	0.7694
	25	Pottery, clay products	1.3211	1.1396	1.0585	0.9167	0.4709	3.0315	2.4165	2.5926	2.3704	1.4355
	26	Cement, concrete products	3.6693	2.3072	1.5287	1.5219	1.5470	6.3555	3.9974	3.6792	3.5517	3.6170
	27	Other nonmetallic mineral products	1.3176	1.1320	1.0817	1.0388	0.6906	3.8104	3.0151	2.6541	2.5968	2.1628
	28	Pig iron & crude steel	2.6371	2.1717	2.3825	2.4390	3.1327	9.6312	8.1988	9.8425	9.0068	9.6250
	29	Primary iron, steel products	0.2409	0.1936	0.1398	0.1125	0.0886	4.9757	4.0218	4.5662	4.2851	4.0764
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.5750	0.3256	0.1840	0.0832	0.1049	1.5282	0.8836	0.6578	0.5000	0.5987
	31	Fabricated metal products-p	0.1545	0.0849	0.1547	0.1621	0.2020	2.0276	1.5572	1.6379	1.4068	1.5860
	32	Machinery, equipment of general purpose-p	0.0946	0.0364	0.0597	0.0823	0.0591	1.0536	0.7991	0.8563	0.9033	0.1899
	33	Wholesale, retail trade	0.2799	0.2652	0.2511	0.1291	0.1310	0.9188	0.8022	0.8154	0.5580	0.6843
	34	Eating, drinking places, hotels, other lodging places	0.3280	0.3266	0.1963	0.2044	0.1668	0.9825	0.9951	0.8662	0.8204	0.7763
	35	Transportation & warehousing-p	1.1645	1.3721	1.5601	1.4817	1.0834	2.4817	2.6217	3.1757	3.2003	2.7046
	36	Public administration, defense	0.2640	0.2272	0.1715	0.1269	0.0669	1.0415	0.8549	0.7365	0.5487	0.4139
	37	Gas, water supply	0.0262	0.0266	0.0530	0.0599	0.0510	1.7555	1.0140	1.3899	1.3426	1.3529
	38	Medical, health services, social security-p	0.2682	0.5540	0.4715	0.4150	0.0000	0.9527	1.3350	1.2550	1.2617	0.0000
	39	Other services-p	0.1106	0.1624	0.2519	0.1960	0.1338	0.5142	0.5979	0.9181	0.8485	0.7660
	40	Crops-p	0.0372	0.0462	0.0603	0.0779	0.1991	0.2663	0.3083	0.3513	0.3943	0.5989
	41	Livestock breeding	0.1711	0.1237	0.1776	0.1657	0.0529	0.8077	0.8384	0.7739	0.8101	0.7662
	42	Forestry products	0.0032	0.0229	0.0166	0.0358	0.0265	0.0982	0.1256	0.1355	0.2239	0.1491
	43	Meat, dairy products	0.0583	0.0548	0.0571	0.0460	0.0295	0.8540	0.7812	0.8057	0.6928	0.6200
	44	Processed seafood products	0.1236	0.0785	0.0726	0.0692	0.0398	1.2730	1.3874	1.3593	1.1371	0.9369
non energy and energy less intensive	45	Polished grains, flour, milled cereals	0.0089	0.0130	0.0161	0.0153	0.0085	0.3203	0.3953	0.4416	0.4526	0.6289
	46	Bakery, confectionery products, noodles	0.1759	0.1537	0.1359	0.1513	0.0830	1.0959	0.9223	0.7938	0.8729	0.7674
	47	Seasonings, fats and oils	0.2973	0.2116	0.1472	0.1695	0.0776	1.3761	0.9856	0.8152	0.8730	0.7329
	48	Canned or cured fruits, vegetables, misc. food preparations	0.1992	0.2032	0.1729	0.1579	0.0740	0.8970	0.7517	0.7431	0.7039	0.6032
	49	Beverages	0.1764	0.1217	0.1021	0.0849	0.0432	0.8785	0.6526	0.6834	0.6070	0.5009
	50	Prepared livestock feeds	0.0167	0.0351	0.0465	0.0550	0.0424	0.6191	0.6377	0.6189	0.6084	0.8293

51	Tobacco products	0.0131	0.0182	0.0145	0.0151	0.0119	0.1828	0.1809	0.1391	0.1561	0.1973
52	Fiber yarn-p	0.1170	0.1459	0.1544	0.1241	0.0637	1.6351	1.4738	1.5563	1.3512	1.0673
53	Wearing apparels, apparel accessories	0.0851	0.0950	0.0801	0.0761	0.0329	1.3932	1.2343	0.9176	0.8951	0.4968
54	Other fabricated textile products	0.0914	0.1038	0.1143	0.0831	0.0511	1.4760	1.2791	1.1628	1.2804	0.9429
55	Leather, fur products	0.0562	0.0581	0.0603	0.0668	0.0322	0.6863	0.6807	0.6494	0.7474	0.8640
56	Wood, wooden products-p	0.0542	0.1011	0.1229	0.1132	0.0508	0.7112	0.6594	0.7769	0.8159	0.7137
57	Pulp, paper-p	0.1539	0.1327	0.0847	0.0984	0.0902	1.3353	1.0199	0.8547	1.0997	1.0055
58	Printing, publishing, reproduction of recorded media	0.0378	0.0380	0.0524	0.0585	0.0550	0.8262	0.6440	0.6635	0.8244	0.7681
59	Synthetic resins, synthetic rubber-p	0.1367	0.1435	0.1204	0.0963	0.0468	2.8381	2.5115	2.7214	2.9549	2.5845
60	Fertilizers, agricultural chemicals-p	0.0689	0.0608	0.0943	0.0959	0.0526	1.5133	1.6463	1.9843	2.3527	1.8790
61	Drugs, cosmetics, soap	0.0920	0.0701	0.0765	0.0647	0.0362	1.0812	0.8580	0.9457	0.8753	0.6484
62	Plastic products	0.1356	0.1121	0.1809	0.1413	0.0737	1.8527	1.4595	1.6815	1.7693	1.2190
63	Rubber products	0.2287	0.1631	0.1532	0.1721	0.1010	1.7303	1.2015	1.1736	1.2547	1.0977
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.1938	0.1749	0.1432	0.0855	0.0695	1.4589	0.9560	0.8511	0.6062	0.6315
65	Fabricated metal products-p	0.1295	0.0565	0.0637	0.0659	0.0539	2.9325	1.7610	1.9181	1.9195	1.6960
66	Machinery, equipment of general purpose-p	0.0530	0.0515	0.0401	0.0536	0.0414	0.8200	0.8925	0.7926	0.8618	0.8266
67	Machinery, equipment of special purpose	0.0663	0.0267	0.0358	0.0457	0.0273	0.8684	0.5886	0.6485	0.7422	0.5811
68	Electronic machinery, equipment, supplies	0.0682	0.0734	0.0557	0.0546	0.0426	0.9306	0.8393	0.7118	0.6460	0.5596
69	Electronic components, accessories	0.0589	0.0379	0.0334	0.0179	0.0075	1.2414	1.0160	0.7624	0.3867	0.2171
70	Radio, television, communications equipment	0.0297	0.0297	0.0213	0.0160	0.0080	1.0540	0.8935	0.6342	0.3992	0.2753
71	Computer, office equipment	0.0393	0.0154	0.0098	0.0066	0.0026	0.9151	0.9213	0.5702	0.3344	0.1549
72	Household electrical appliances	0.0766	0.0534	0.0387	0.0358	0.0299	1.6919	1.2787	0.9535	0.7750	0.7203
73	Precision instruments	0.0277	0.0130	0.0159	0.0190	0.0108	0.3739	0.2863	0.2654	0.2787	0.2249
74	Motor vehicles	0.0994	0.0685	0.0487	0.0512	0.0315	1.4639	1.2639	1.0357	1.0643	0.8491
75	Ship building, repairing	0.0424	0.0389	0.0285	0.0354	0.0325	1.4453	1.1895	0.8860	0.8282	1.2365
76	Other transportation equipment	0.0437	0.0257	0.0311	0.0360	0.0263	0.5691	0.4188	0.3909	0.4877	0.4087
77	Furniture	0.0666	0.0993	0.0894	0.0937	0.0384	1.2157	0.9640	0.9432	0.9075	0.7304
78	Other manufacturing products	0.0959	0.0821	0.0769	0.0768	0.0618	1.1462	0.8566	0.7386	0.7801	0.6132

79	Building construction, repair	0.0291	0.0302	0.0353	0.0431	0.0729	0.9384	0.7113	0.8841	0.9437	0.9279
80	Civil Engineering	0.1425	0.1444	0.1017	0.1021	0.2735	1.1336	0.9124	1.0797	1.1388	1.4792
81	Transportation, warehousing-p	0.1036	0.2225	0.1111	0.0895	0.0000	0.3615	0.5857	0.3245	0.2742	0.0000
82	Communications, broadcasting	0.1114	0.0636	0.0429	0.0281	0.0263	0.6206	0.3854	0.3384	0.3169	0.3348
83	Finance, insurance	0.0500	0.0569	0.0367	0.0266	0.0197	0.4181	0.3665	0.2956	0.2273	0.2135
84	Real estate agencies, rental	0.0464	0.0303	0.0319	0.0183	0.0259	0.3658	0.3252	0.4168	0.2875	0.3210
85	Business services	0.1041	0.0932	0.1026	0.0666	0.0503	0.6143	0.5164	0.4671	0.3355	0.3254
86	Educational, research services	0.0836	0.0887	0.0975	0.1171	0.0909	0.2593	0.2756	0.3638	0.4381	0.4691
87	Medical, health services, social security	0.1658	0.1141	0.1003	0.0665	0.1137	0.6752	0.5152	0.5409	0.5610	0.6966
88	Culture, recreational services	0.2158	0.1472	0.1260	0.1003	0.1061	0.8895	0.6420	0.6773	0.5269	0.5010
89	Other services	0.1892	0.1893	0.0981	0.1172	0.0951	1.0147	0.9363	0.7102	0.7202	0.6123
90	Unclassified activities	0.0582	0.0537	0.0683	0.0557	0.0106	0.9044	0.9325	0.9354	0.9058	0.7246

Appendix 7. Decomposition Results of the Direct GHG Emissions for Three Effects

sector		total effect (D_{tot})				social effect (D'_{soc})				technical effect (D'_{tech})			
		'85-'90	'90-'95	'95-'00	'00-'05	'85-'90	'90-'95	'95-'00	'00-'05	'85-'90	'90-'95	'95-'00	'00-'05
energy	1 coal	0.0003	0.0001	0.0001	0.0001	-0.0007	-0.0015	-0.0004	0.0000	0.0015	0.0018	-0.0013	0.0000
	2 fuel	0.0053	0.0125	0.0055	-0.0003	-0.0014	0.0028	-0.0004	-0.0026	-0.0052	0.0079	-0.0001	-0.0039
	3 nfuel	0.0037	0.0015	0.0003	0.0014	0.0010	-0.0004	-0.0003	0.0011	-0.0050	-0.0014	-0.0003	0.0000
	4 gas	0.0352	0.0296	0.0072	0.0010	0.0307	0.0146	0.0040	0.0007	-0.0045	-0.0181	-0.0213	-0.0042
	5 lelec	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	6 felec	0.1044	0.4525	0.2599	0.1098	-0.1608	0.1322	0.0702	0.0121	-0.1136	0.0346	0.0881	-0.0864
	7 nap	0.0007	0.0006	0.0005	0.0000	0.0002	0.0001	0.0003	0.0000	-0.0006	-0.0005	-0.0002	-0.0001
	8 heat	0.0032	0.0053	0.0092	-0.0009	0.0007	0.0026	0.0068	-0.0025	-0.0027	-0.0032	0.0043	-0.0038
non energy and energy intensive	9 Crops-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
	10 Fishery products	0.0042	0.0012	-0.0010	-0.0002	0.0010	-0.0033	-0.0023	-0.0005	0.0029	0.0004	-0.0002	-0.0006
	11 Metallic minerals	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	12 Nonmetallic minerals	0.0007	0.0005	-0.0002	0.0001	0.0003	-0.0002	-0.0004	0.0000	0.0001	0.0002	-0.0001	0.0001
	13 Sugar, starches	0.0003	-0.0001	0.0000	0.0000	0.0000	-0.0003	0.0000	0.0000	0.0000	-0.0002	0.0000	-0.0001
	14 Fiber yarn	0.0001	-0.0002	0.0001	0.0000	-0.0001	-0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001
	15 Fiber fabrics-p	0.0018	0.0023	-0.0013	0.0002	0.0008	0.0007	-0.0018	0.0001	-0.0007	0.0004	-0.0004	-0.0004
	16 Wood, wooden products-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	17 Pulp, paper-p	0.0009	0.0003	0.0002	0.0000	0.0002	-0.0004	0.0000	0.0000	-0.0003	-0.0004	0.0000	-0.0002
	18 Organic basic chemical products	0.0248	0.0590	0.0297	0.0240	0.0089	0.0286	0.0085	0.0126	-0.0126	0.0148	-0.0020	-0.0015
	19 Inorganic basic chemical products	0.0027	0.0006	0.0007	0.0002	-0.0004	-0.0016	0.0002	0.0000	-0.0031	-0.0018	-0.0003	-0.0004
	20 Synthetic resins, synthetic rubber-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	21 Chemical fibers	0.0001	-0.0002	0.0001	-0.0001	-0.0009	-0.0007	0.0000	-0.0001	-0.0010	-0.0004	-0.0001	0.0000
	22 Fertilizers, agricultural chemicals-p	-0.0005	0.0000	-0.0003	-0.0001	-0.0027	-0.0014	-0.0006	-0.0002	-0.0012	-0.0004	-0.0003	-0.0002
	23 Other chemical products	0.0004	0.0001	0.0001	0.0000	0.0003	-0.0001	0.0000	0.0000	0.0001	-0.0002	0.0000	-0.0001
	24 Glass products	0.0033	0.0007	0.0002	-0.0001	0.0010	-0.0015	-0.0003	-0.0002	0.0000	-0.0021	-0.0003	-0.0007

non energy and energy less intensive	25	Pottery, clay products	0.0056	0.0004	-0.0009	-0.0003	0.0029	-0.0028	-0.0017	-0.0004	-0.0009	-0.0004	-0.0004	-0.0006
	26	Cement, concrete products	0.0130	0.0127	-0.0026	0.0011	-0.0214	-0.0101	-0.0085	-0.0011	-0.0350	-0.0166	-0.0001	0.0003
	27	Other nonmetallic mineral products	0.0070	0.0045	0.0002	0.0000	0.0037	-0.0003	-0.0017	-0.0006	-0.0011	-0.0004	-0.0003	-0.0016
	28	Pig iron & crude steel	0.0416	0.0485	0.0099	0.0359	0.0039	0.0001	-0.0116	0.0232	-0.0161	0.0079	0.0017	0.0221
	29	Primary iron, steel products	0.0011	0.0007	0.0002	0.0001	0.0002	-0.0003	0.0000	0.0000	-0.0005	-0.0005	-0.0002	-0.0002
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.0004	0.0002	0.0000	0.0001	-0.0001	-0.0001	-0.0001	0.0000	-0.0006	-0.0004	-0.0002	0.0000
	31	Fabricated metal products-p	0.0001	0.0003	0.0001	0.0004	0.0000	0.0002	0.0000	0.0003	-0.0001	0.0002	0.0000	0.0001
	32	Machinery, equipment of general purpose-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	33	Wholesale, retail trade	0.0041	0.0015	-0.0003	0.0006	0.0012	-0.0019	-0.0011	0.0003	-0.0003	-0.0003	-0.0018	0.0000
	34	Eating, drinking places, hotels, other lodging places	0.0046	0.0004	0.0008	0.0000	0.0030	-0.0016	0.0002	-0.0003	-0.0001	-0.0018	0.0001	-0.0003
	35	Transportation & warehousing-p	0.0656	0.0560	0.0211	0.0026	0.0151	-0.0197	-0.0104	-0.0088	0.0182	0.0172	-0.0055	-0.0249
	36	Public administration, defense	0.0015	0.0006	0.0001	-0.0001	0.0003	-0.0006	-0.0002	-0.0002	-0.0004	-0.0006	-0.0003	-0.0003
	37	Gas, water supply	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	38	Medical, health services, social security-p	0.0007	0.0008	0.0001	-0.0007	0.0005	0.0002	-0.0001	-0.0007	0.0003	-0.0002	-0.0001	0.0000
	39	Other services-p	0.0003	0.0011	0.0003	-0.0001	0.0001	0.0006	0.0000	-0.0002	0.0001	0.0004	-0.0003	-0.0003
	40	Crops-p	0.0001	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0003
	41	Livestock breeding	0.0000	0.0003	0.0000	-0.0001	-0.0001	0.0001	-0.0001	-0.0001	-0.0001	0.0001	0.0000	-0.0001
	42	Forestry products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	43	Meat, dairy products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	44	Processed seafood products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	45	Polished grains, flour, milled cereals	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	46	Bakery, confectionery products, noodles	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	47	Seasonings, fats and oils	0.0000	0.0000	0.0000	0.0000	-0.0002	-0.0001	0.0000	0.0000	-0.0001	-0.0001	0.0000	0.0000
	48	Canned or cured fruits, vegetables, misc. food preparations	0.0002	0.0001	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001
	49	Beverages	0.0001	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000
	50	Prepared livestock feeds	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	51	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

52	Fiber yarn-p	0.0003	0.0002	0.0000	-0.0001	0.0000	-0.0002	-0.0001	-0.0001	0.0001	0.0000	-0.0001	-0.0001
53	Wearing apparels, apparel accessories	0.0002	-0.0001	0.0000	0.0000	0.0000	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Other fabricated textile products	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Leather, fur products	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	Wood, wooden products-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	Pulp, paper-p	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000
58	Printing, publishing, reproduction of recorded media	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
59	Synthetic resins, synthetic rubber-p	0.0005	0.0000	0.0001	0.0000	0.0003	-0.0002	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0001
60	Fertilizers, agricultural chemicals-p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
61	Drugs, cosmetics, soap	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	Plastic products	0.0002	0.0004	0.0001	0.0000	0.0001	0.0001	0.0000	-0.0001	-0.0001	0.0002	-0.0001	-0.0002
63	Rubber products	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000	0.0000	-0.0001
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.0003	0.0002	0.0000	0.0000	0.0001	0.0000	-0.0001	0.0000	0.0000	-0.0001	-0.0001	0.0000
65	Fabricated metal products-p	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000
66	Machinery, equipment of general purpose-p	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
67	Machinery, equipment of special purpose	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000
68	Electronic machinery, equipment, supplies	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
69	Electronic components, accessories	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	Radio, television, communications equipment	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	Computer, office equipment	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
72	Household electrical appliances	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
73	Precision instruments	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
74	Motor vehicles	0.0004	0.0002	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000	-0.0001
75	Ship building, repairing	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
76	Other transportation equipment	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
77	Furniture	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
78	Other manufacturing products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
79	Building construction, repair	0.0001	0.0000	0.0000	0.0002	0.0001	-0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001

80	Civil Engineering	0.0008	-0.0002	0.0001	0.0010	0.0001	-0.0008	0.0000	0.0008	0.0000	-0.0004	0.0000	0.0012
81	Transportation, warehousing-p	0.0003	0.0000	0.0000	-0.0001	0.0002	-0.0001	0.0000	-0.0001	0.0002	-0.0002	0.0000	0.0000
82	Communications, broadcasting	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000
83	Finance, insurance	0.0002	0.0000	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000
84	Real estate agencies, rental	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	-0.0001	0.0000
85	Business services	0.0003	0.0004	0.0001	0.0000	0.0001	0.0001	-0.0001	0.0000	0.0000	0.0000	-0.0002	-0.0001
86	Educational, research services	0.0002	0.0003	0.0003	0.0003	0.0001	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	-0.0002
87	Medical, health services, social security	0.0001	0.0002	0.0001	0.0003	-0.0001	0.0000	0.0000	0.0003	-0.0001	0.0000	-0.0001	0.0002
88	Culture, recreational services	0.0001	0.0001	0.0001	0.0001	-0.0001	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0000
89	Other services	0.0001	0.0000	0.0001	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000
90	Unclassified activities	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001

Appendix 8. Decomposition Results of the Embodied GHG Emissions for Three Effects

sector		total effect (D_{tot})				social effect (D'_{soc})				technical effect (D'_{tech})			
		'85-'90	'90-'95	'95-'00	'00-'05	'85-'90	'90-'95	'95-'00	'00-'05	'85-'90	'90-'95	'95-'00	'00-'05
energy	1 coal	0.0175	0.0027	0.0031	0.0067	-0.0490	-0.0538	-0.0152	-0.0012	0.0004	0.0004	-0.0007	-0.0001
	2 fuel	0.0821	0.1765	0.0668	-0.0045	-0.0212	0.0395	-0.0047	-0.0369	-0.0047	0.0018	-0.0017	-0.0050
	3 nfuel	0.0037	0.0021	0.0005	0.0029	0.0010	-0.0006	-0.0006	0.0022	-0.0024	-0.0005	-0.0001	0.0000
	4 gas	0.0294	0.0330	0.0229	0.0217	0.0257	0.0163	0.0127	0.0152	-0.0022	-0.0062	-0.0082	-0.0016
	5 lelec	0.0006	0.0001	-0.0001	0.0000	0.0006	-0.0002	-0.0002	0.0000	0.0002	-0.0001	-0.0001	0.0000
	6 felec	0.0463	0.2037	0.1209	0.0492	-0.0713	0.0595	0.0326	0.0054	-0.0401	0.0250	0.0068	-0.0550
	7 nap	0.0046	0.0059	0.0078	0.0009	0.0012	0.0010	0.0046	-0.0010	-0.0002	-0.0002	-0.0001	0.0000
	8 heat	0.0017	0.0030	0.0066	-0.0006	0.0004	0.0015	0.0049	-0.0017	-0.0019	-0.0007	0.0024	-0.0036
non energy and energy intensive	9 Crops-p	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	10 Fishery products	0.0026	0.0007	-0.0007	-0.0001	0.0006	-0.0020	-0.0016	-0.0004	0.0013	0.0006	0.0000	-0.0003
	11 Metallic minerals	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	12 Nonmetallic minerals	0.0006	0.0004	-0.0002	0.0001	0.0003	-0.0002	-0.0004	0.0000	-0.0001	0.0002	-0.0001	0.0002
	13 Sugar, starches	0.0003	-0.0001	0.0000	0.0000	0.0000	-0.0003	0.0000	-0.0001	-0.0001	-0.0001	0.0000	-0.0001
	14 Fiber yarn	0.0006	-0.0005	0.0002	-0.0001	-0.0004	-0.0011	0.0001	-0.0002	-0.0002	-0.0005	0.0001	-0.0001
	15 Fiber fabrics-p	0.0014	0.0018	-0.0013	0.0003	0.0006	0.0005	-0.0018	0.0001	-0.0007	0.0007	0.0001	-0.0004
	16 Wood, wooden products-p	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	17 Pulp, paper-p	0.0011	0.0003	0.0003	0.0001	0.0002	-0.0005	-0.0001	-0.0001	-0.0008	0.0000	0.0002	-0.0001
	18 Organic basic chemical products	0.0315	0.0767	0.0405	0.0364	0.0113	0.0372	0.0116	0.0190	-0.0037	0.0078	0.0073	0.0000
	19 Inorganic basic chemical products	0.0024	0.0005	0.0009	0.0003	-0.0003	-0.0015	0.0002	0.0000	-0.0026	-0.0009	-0.0002	-0.0004
	20 Synthetic resins, synthetic rubber-p	-0.0001	0.0001	0.0001	0.0002	-0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
	21 Chemical fibers	0.0003	-0.0009	0.0003	-0.0007	-0.0023	-0.0025	-0.0001	-0.0008	-0.0009	-0.0002	0.0000	-0.0002
	22 Fertilizers, agricultural chemicals-p	-0.0008	0.0000	-0.0005	-0.0002	-0.0042	-0.0019	-0.0009	-0.0003	-0.0021	-0.0011	-0.0002	-0.0003
	23 Other chemical products	0.0012	0.0003	0.0004	0.0000	0.0007	-0.0004	0.0001	-0.0001	-0.0001	-0.0001	0.0000	-0.0002
	24 Glass products	0.0025	0.0005	0.0002	-0.0002	0.0007	-0.0011	-0.0003	-0.0003	-0.0006	-0.0010	-0.0002	-0.0007
	25 Pottery, clay products	0.0037	0.0003	-0.0007	-0.0003	0.0019	-0.0018	-0.0013	-0.0004	-0.0009	0.0003	-0.0002	-0.0004

non energy and energy less intensive	26	Cement, concrete products	0.0067	0.0074	-0.0019	0.0008	-0.0111	-0.0059	-0.0063	-0.0008	-0.0182	-0.0020	-0.0005	0.0002
	27	Other nonmetallic mineral products	0.0057	0.0034	0.0001	0.0000	0.0030	-0.0003	-0.0013	-0.0005	-0.0014	-0.0008	-0.0001	-0.0007
	28	Pig iron & crude steel	0.0461	0.0559	0.0121	0.0393	0.0043	0.0002	-0.0142	0.0254	-0.0148	0.0180	-0.0080	0.0064
	29	Primary iron, steel products	0.0069	0.0049	0.0026	0.0020	0.0012	-0.0020	-0.0005	0.0005	-0.0027	0.0015	-0.0007	-0.0005
	30	Nonferrous metal ingots, primary nonferrous metal products-p	0.0004	0.0002	0.0000	0.0001	-0.0001	-0.0001	-0.0001	0.0001	-0.0005	-0.0002	-0.0001	0.0001
	31	Fabricated metal products-p	0.0003	0.0013	0.0004	0.0010	-0.0002	0.0007	0.0000	0.0008	-0.0003	0.0001	-0.0002	0.0002
	32	Machinery, equipment of general purpose-p	0.0000	0.0002	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0002
	33	Wholesale, retail trade	0.0038	0.0014	-0.0003	0.0009	0.0011	-0.0018	-0.0012	0.0005	-0.0008	0.0001	-0.0012	0.0005
	34	Eating, drinking places, hotels, other lodging places	0.0041	0.0004	0.0011	-0.0001	0.0027	-0.0016	0.0003	-0.0004	0.0000	-0.0005	-0.0001	-0.0001
	35	Transportation & warehousing-p	0.0391	0.0321	0.0138	0.0020	0.0090	-0.0113	-0.0068	-0.0067	0.0036	0.0147	0.0005	-0.0101
	36	Public administration, defense	0.0017	0.0007	0.0001	-0.0001	0.0003	-0.0007	-0.0003	-0.0003	-0.0006	-0.0004	-0.0004	-0.0002
	37	Gas, water supply	0.0002	0.0001	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000	-0.0003	0.0001	0.0000	0.0000
	38	Medical, health services, social security-p	0.0006	0.0006	0.0001	-0.0007	0.0004	0.0002	-0.0001	-0.0007	0.0001	0.0000	0.0000	0.0000
	39	Other services-p	0.0004	0.0012	0.0004	-0.0001	0.0002	0.0006	0.0000	-0.0003	0.0001	0.0004	-0.0001	-0.0001
	40	Crops-p	0.0001	0.0001	0.0001	0.0004	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000	0.0002
	41	Livestock breeding	0.0000	0.0004	-0.0001	-0.0001	-0.0002	0.0001	-0.0002	-0.0002	0.0000	0.0000	0.0000	0.0000
	42	Forestry products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	43	Meat, dairy products	0.0001	0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000
	44	Processed seafood products	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	45	Polished grains, flour, milled cereals	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	46	Bakery, confectionery products, noodles	0.0002	0.0001	0.0000	-0.0001	0.0000	-0.0001	0.0000	-0.0001	-0.0001	0.0000	0.0000	0.0000
	47	Seasonings, fats and oils	0.0001	0.0000	0.0000	-0.0001	-0.0002	-0.0002	0.0000	-0.0001	-0.0002	-0.0001	0.0000	0.0000
	48	Canned or cured fruits, vegetables, misc. food preparations	0.0002	0.0001	0.0000	0.0000	0.0001	-0.0001	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000
	49	Beverages	0.0001	0.0001	0.0000	0.0000	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	0.0000	0.0000	0.0000
	50	Prepared livestock feeds	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	51	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	52	Fiber yarn-p	0.0009	0.0004	0.0002	-0.0003	0.0001	-0.0005	-0.0002	-0.0004	-0.0002	0.0001	-0.0002	-0.0002

53	Wearing apparels, apparel accessories	0.0007	-0.0002	0.0000	-0.0001	0.0001	-0.0007	-0.0001	-0.0001	-0.0002	-0.0003	0.0000	-0.0001
54	Other fabricated textile products	0.0002	0.0003	0.0001	0.0000	0.0001	0.0001	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0001
55	Leather, fur products	0.0003	-0.0001	0.0000	0.0000	0.0001	-0.0003	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
56	Wood, wooden products-p	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	Pulp, paper-p	0.0003	0.0000	0.0001	0.0000	0.0000	-0.0002	0.0000	0.0000	-0.0001	-0.0001	0.0001	0.0000
58	Printing, publishing, reproduction of recorded media	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
59	Synthetic resins, synthetic rubber-p	0.0026	0.0000	0.0009	-0.0002	0.0016	-0.0014	0.0004	-0.0005	-0.0003	0.0002	0.0002	-0.0003
60	Fertilizers, agricultural chemicals-p	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
61	Drugs, cosmetics, soap	0.0003	0.0002	0.0001	0.0000	0.0001	-0.0001	0.0000	0.0000	-0.0001	0.0000	0.0000	-0.0001
62	Plastic products	0.0009	0.0013	0.0005	-0.0001	0.0004	0.0004	-0.0001	-0.0003	-0.0003	0.0002	0.0001	-0.0005
63	Rubber products	0.0003	0.0003	0.0002	-0.0001	0.0000	0.0000	0.0000	-0.0002	-0.0002	0.0000	0.0000	-0.0001
64	Nonferrous metal ingots, primary nonferrous metal products-p	0.0005	0.0003	0.0000	0.0000	0.0002	0.0000	-0.0001	0.0000	-0.0002	-0.0001	-0.0001	0.0000
65	Fabricated metal products-p	0.0000	0.0006	-0.0001	0.0001	-0.0003	0.0002	-0.0002	0.0001	-0.0003	0.0000	0.0000	-0.0001
66	Machinery, equipment of general purpose-p	0.0005	0.0003	0.0001	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000
67	Machinery, equipment of special purpose	0.0001	0.0003	0.0002	0.0000	0.0000	0.0001	0.0001	-0.0001	-0.0001	0.0000	0.0001	-0.0001
68	Electronic machinery, equipment, supplies	0.0005	0.0002	0.0003	0.0000	0.0003	-0.0001	0.0001	-0.0001	-0.0001	-0.0001	0.0000	-0.0001
69	Electronic components, accessories	0.0005	0.0005	0.0003	0.0001	0.0002	0.0002	0.0002	0.0001	-0.0001	-0.0002	-0.0003	-0.0002
70	Radio, television, communications equipment	0.0003	0.0000	0.0001	0.0000	0.0002	-0.0001	0.0001	0.0000	0.0000	-0.0001	-0.0001	0.0000
71	Computer, office equipment	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
72	Household electrical appliances	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
73	Precision instruments	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
74	Motor vehicles	0.0018	0.0011	0.0007	0.0001	0.0012	0.0000	0.0002	-0.0001	-0.0002	-0.0004	0.0000	-0.0004
75	Ship building, repairing	-0.0001	0.0001	0.0001	0.0001	-0.0002	0.0000	0.0001	0.0000	-0.0001	0.0000	0.0000	0.0001
76	Other transportation equipment	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
77	Furniture	0.0002	0.0001	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
78	Other manufacturing products	0.0002	0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	-0.0001	-0.0001	0.0000	0.0000	0.0000
79	Building construction, repair	0.0010	0.0002	-0.0001	0.0009	0.0005	-0.0004	-0.0003	0.0008	-0.0003	0.0003	0.0001	0.0000
80	Civil Engineering	0.0017	-0.0004	0.0004	0.0024	0.0002	-0.0018	-0.0001	0.0020	-0.0007	0.0004	0.0001	0.0008

81	Transportation, warehousing-p	0.0002	0.0000	0.0000	-0.0001	0.0002	-0.0001	0.0000	-0.0001	0.0001	-0.0001	0.0000	0.0000
82	Communications, broadcasting	0.0001	0.0001	0.0001	0.0002	0.0000	0.0000	0.0001	0.0001	-0.0001	0.0000	0.0000	0.0000
83	Finance, insurance	0.0004	0.0001	0.0000	0.0000	0.0002	-0.0001	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000
84	Real estate agencies, rental	0.0002	0.0004	0.0002	0.0003	0.0000	0.0001	0.0001	0.0002	-0.0001	0.0001	-0.0002	0.0001
85	Business services	0.0005	0.0006	0.0001	0.0001	0.0002	0.0002	-0.0001	0.0000	-0.0001	-0.0001	-0.0002	0.0000
86	Educational, research services	0.0002	0.0003	0.0003	0.0005	0.0001	0.0000	0.0001	0.0003	0.0000	0.0001	0.0001	0.0001
87	Medical, health services, social security	0.0001	0.0002	0.0001	0.0007	-0.0001	0.0000	0.0000	0.0006	-0.0001	0.0000	0.0000	0.0002
88	Culture, recreational services	0.0001	0.0002	0.0001	0.0002	-0.0001	0.0000	0.0000	0.0002	-0.0001	0.0000	-0.0001	0.0000
89	Other services	0.0001	-0.0001	0.0001	0.0000	0.0000	-0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
90	Unclassified activities	0.0003	0.0004	0.0002	-0.0004	0.0001	0.0001	0.0000	-0.0004	0.0000	0.0000	0.0000	-0.0001

List of Publications

Original papers

- (1) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: Analysis of Sectoral Energy Use Pattern with Energy Input-Output Analysis, *J. of KOSEE*, 2008;17(3):pp145-152. (Chapter 2)
- (2) Whan-Sam Chung and Susumu Tohno, 2008: Convertibility of Monetary and Physical Input-output Analysis- an Application to Energy Sources -, *Korean J. of LCA*, 2008;9(1):pp 47-55. (Chapter 2)
- (3) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: An Estimation of GHG Emission Intensities from Energy Use- Energy Input-output Approach -, *Korean J. of LCA*, 2008;9(1):pp 69-77. (Chapter 3)
- (4) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: An Analysis of Sectoral GHG Emission Intensity from Energy Use in Korea, *J. of KOTIS*, 2008; 11(2): pp264-286. (Chapter 3)
- (5) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2009: An estimation of energy and GHG emission intensity caused by energy consumption in Korea: An energy IO approach, *Applied Energy*, 2009;86:1902-1914. (Chapter 3)
- (6) Whan-Sam Chung and Susumu Tohno, 2009: A time-series energy input-output analysis for building an infrastructure for the energy and environment policy in Korea, *Energy and Environment*, 2009;20(6):875-899. (Chapter 4)
- (7) Whan-Sam Chung, Susumu Tohno and Ki-Hong Choi, 2011: Socio-Technological Impact Analysis using an Energy IO Approach to GHG Emissions Issues in Korea, *Applied Energy*, 2011;88:3747-3758. (Chapter 5)
- (8) Whan-Sam Chung and Susumu Tohno, 2013: Can IDA give a clue in understanding industry's GHG footprint ?, *Energy and Environment*, in submission. (Chapter 6)

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A goal towards fulfilling the purpose of my studies might have been easier to achieve if I were merely following 'what I can' rather than 'what I have to do'. I surmise I have surmounted a peak. I would like to enjoy the song of a blue bird at this moment. The time is prime to summarize, and perhaps plan for the next trail of study.

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On a personal note, I cherish the memory of climbing Mt. Daimonji in the background of Yoshida Campus, together with the students in the lab. The vitality of young students' laughter as they leaped the big jump in the kanji Dai(大) formation, high up into the sky, still flashes before my eyes and resound in my ears. Their exotic-sounding names, sometimes mismatched with their familiar-looking faces, are forever etched onto my cerebral cortex like hologram tatoos, and will remain with me forever. I hope to see them again one day. I picture them dreaming great dreams for our global village, as well as their endeared homeland, and bearing much fruit in their endeavors to benefit all.

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Kyoto University is known for nurturing an academic tradition excelling in both liberty and responsibility, and so has my research lab. I pledge to be an alumnus adding to the reputation of this great tradition.